The evolution of the Holocene wetland landscape of the Humberhead Levels from a fossil insect perspective.

Nicola Jane Whitehouse

Volume 1 of 2

"The Earth is not a mere fragment of dead history, stratum upon stratum like the leaves of a book, to be studied by geologists and antiquaries chiefly, but living poetry, like the leaves of a tree, which precedes flowers and fruit - not a fossil earth, but a living earth..." (Henry David Thoreau, Walden, Spring, in Homan 1991, 109)

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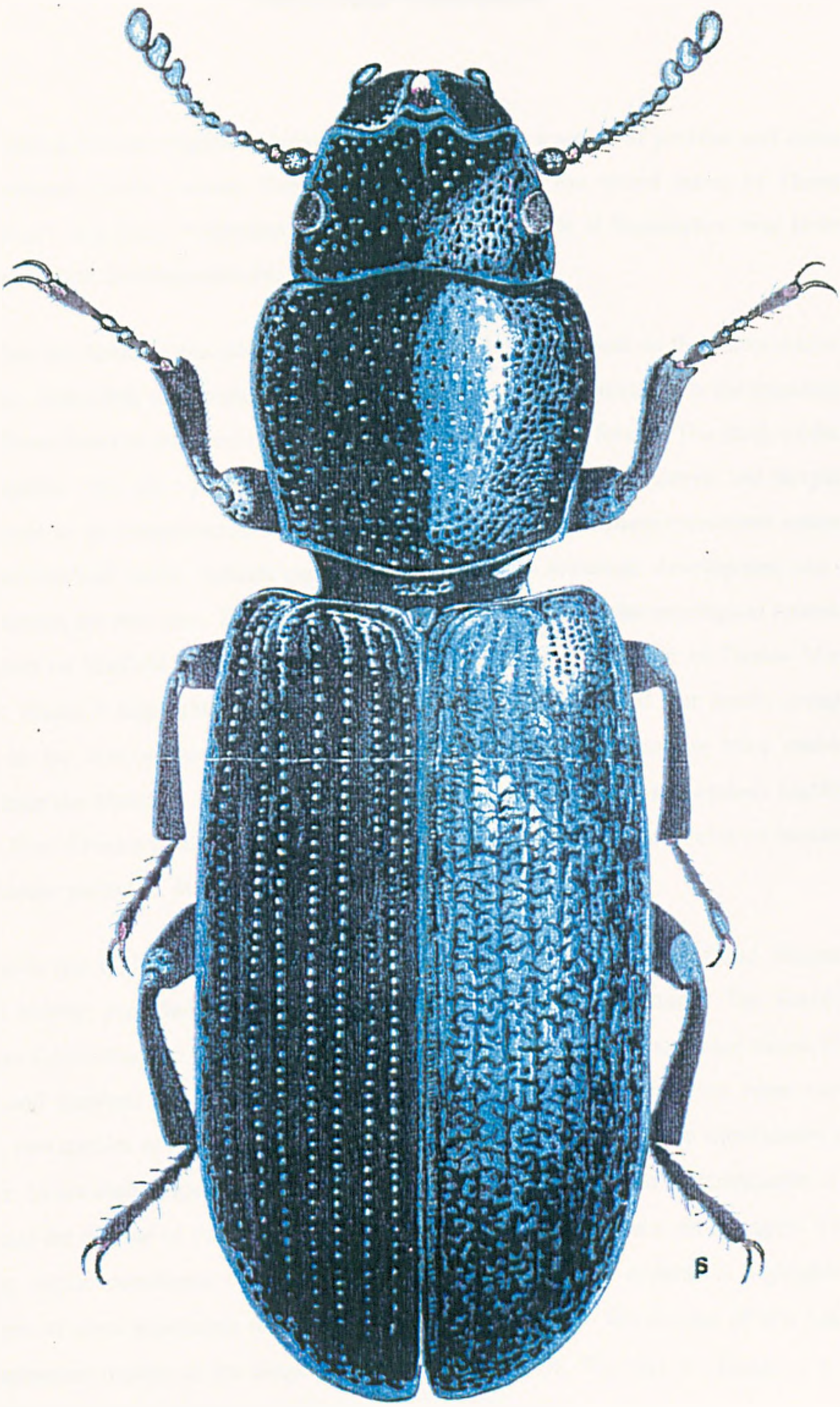
Frontpiece: *Temnochila caerulea* (painting by Peter Skidmore), found as a fossil in deposits dating to *c.* > 3350-3100 cal BC (*c.* > 4500 BP) from Thorne Moors.



This thesis is dedicated to all those people who have tirelessly campaigned to save Thorne and Hatfield Moors.

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Abstract

Palaeoentomological investigations have been carried out on a series of profiles and contexts in the Humberhead Levels (eastern England), principally from the raised mires of Thorne and Hatfield Moors, and from floodplains of the rivers Torne and Idle at Rossington, near Doncaster, and Misterton Carr, Nottinghamshire.

Research has attempted to elucidate the effect of peatland development on the composition of the insect fauna, with particular emphasis on Hatfield Moors, as well as investigate the transition from *Quercus-Pinus* forest to mire and the faunal characteristics of those forests. The study of the fossil insects, together with other palaeoecological evidence, has enabled the genesis and development of these mires to be reconstructed in some detail. However, the palaeoenvironmental record from Thorne and Hatfield Moors indicate significant differences in initiation, development and rate of growth between the two sites. The research highlights the valuable palaeoecological record of the peat deposits on Hatfield Moors, which have long been ignored in favour of Thorne Moors. In particular, research highlights the importance of *Pinus* woodland and wet heath, components reflected in the invertebrates today. The study of the floodplain deposits have enabled the research from the Moors to be placed within a regional context. Faunal successions highlight the transition from *Urwald* (undisturbed woodland), *c.* 4000 cal BC, to a largely cleared landscape by the late Roman period (*c.* 400 cal AD).

The research has highlighted the nature and diversity of Holocene *Urwald* and illustrates the important habitat provided by abundant dead wood within these systems. The fossil record emphasises the contraction in range of many elements of the British Coleopterous fauna, both at a regional and national level. A total of eleven extirpated Coleoptera have been recovered, including two species of beetle previously unknown in the British Isles. The significance of these and other *Urwaldrelikt* species is discussed in relation to the human fragmentation of forest habitats and the decline of *Pinus sylvestris* L. The importance of fire as a natural agent within the landscape, within coniferous woodland and *Pinus*-mire and heath systems is highlighted. The dependence of some pinicolous taxa on fire habitats suggests that the decline of this habitat has had a detrimental impact on the biogeography of some species. The role of climate as a limiting factor in distribution of thermophilous species is also discussed.

List of contents - Volume 1

CHAPTER I: BACKGROUND TO THE HUMBERHEAD LEVELS

CHAPTER II: PREVIOUS PALAEOENVIRONMENTAL RESEARCH IN THE HUMBERHEAD LEVELS

CHAPTER III: PALAEOENTOMOLICAL APPROACHES AND METHODOLOGY

CHAPTER IV: FIELD SURVEY PROGRAMME AND SAMPLING

CHAPTER V: ANALYSIS OF THE FOSSIL INSECT MATERIAL, WITH PARTICULAR EMPHASIS ON A NEW METHODOLOGICAL APPROACH

CHAPTER VI: PALAEOENTOMOLOGICAL RESULTS FROM HATFIELD MOORS

CHAPTER VII: LANDSCAPE DEVELOPMENT OF HATFIELD MOORS; A FOSSIL INSECT PERSPECTIVE

CHAPTER VIII: PALAEOENTOMOLOGICAL RESULTS FROM THORNE MOORS

CHAPTER IX: THORNE AND HATFIELD MOORS: SUMMING UP THE MIRE ASSEMBLAGE RESULTS

CHAPTER X: THE FLOODPLAIN DEPOSITS: PALAEOENTOMOLOGICAL INVESTIGATIONS OF HAYFIELD LODGE FARM, ROSSINGTON, AND MISTERTON CARR

CHAPTER XI. A PALAEOENTOMOLOGICAL PERSPECTIVE ON HOLOCENE WETLAND DEVELOPMENT IN THE HUMBERHEAD LEVELS

CHAPTER 12: PARADISE LOST? THE DEVELOPMENT AND DECLINE OF THE BRITISH ENTOMOFAUNA AND ITS ASSOCITED HABITATS

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INTRODUCTION

The Humberhead Levels consist of the remnants of what was once an extensive complex of raised mires, heathlands and wetlands which developed within this area of Yorkshire. The landscape has formed as the result of natural and anthropogenic processes over the last 10,000 years, in particular, the last 5,000 years. Thorne and Hatfield Moors, although degraded, are the remnants of this landscape. Surrounding the mires are extensive areas of former floodplain wetlands, now drained. Much of the featureless landscape today is largely the result of historical processes of drainage and reclamation and more recently, peat cutting.

Peat bogs support distinctive animal and plant communities, and are the only terrestrial ecosystems which lay down a continuous three-dimensional record of their autochthonous history, as well as that of surrounding animal and plant communities (the allochthonous record). Within their deposits are preserved the remains of their past biodiversity and by detailed studies of these remains, it is possible to document their formation, from inception to their present form. The pioneering palaeoecologist, Sir Harry Godwin (1981), first popularised the concept of peat as an 'archive' of information about the past. The palaeoecological archive thus has immense scientific value to a diverse range of subjects and there are crucial links between peatland palaeoecology and conservation of the present ecosystem and its biological resource (Charman, 1997). The palaeoecological record preserved within these mires and former floodplains offer the potential to investigate the evolution of this landscape, particularly in the light of the extensive peat cutting on the raised mires of Thorne and Hatfield Moors and the intended restoration of these cut-over bogs in the long-term by English Nature.

The Moors have been recognised as particularly sensitive sites for palaeoenvironmental research (Whitehouse *et al.*, 1997). The nature and timing of environmental changes for the Holocene are known in some detail, particularly for Thorne Moors, through palynological and macrofossil analysis as well as peat stratigraphy, supported by radiocarbon dating (*cf.* Smith, 1958a; Turner, 1962; Smith, 1985; Buckland, 1979). A series of research projects were initiated in 1993 following the discovery of extensive areas of well-preserved trees, many of which are charred, over large areas of Thorne Moors. These included palaeoentomological investigations (Roper 1993, 1996;

Whitehouse, 1993, 1997a) and an archaeological and palaeoecological investigation of the buried forest (Dinnin, 1994).

The palaeoentomological investigations highlighted a high number of rare and "locally extinct" Coleoptera (this term is used to indicate those species which presently do not occur in Britain, but which live in mainland Europe) (Whitehouse, 1993). Thorne Moors has proven to be the richest site in terms of records of non-British species recovered and highlights the changing distribution of a range of invertebrate species. The demise of many of the species recovered has been attributed to the destruction of undisturbed primary, forest habitats (*Urwald*) and in particular to the disappearance and lack of continuity of late successional and dead wood habitats (Buckland, 1979). Although the demise of many of these species may be related to forest clearance, there may also have been the possible impact of subtle climatic change. The role of climatic deterioration such as the "Little Ice Age" has still to be clarified, a problem which is related to the lack of suitable deposits of this age. The loss of *Pinus sylvestris* habitats is reflected in many of these invertebrate extirpations; many pinicolous Coleopterous elements appear to have become endangered as *Pinus* woodlands were increasingly restricted to marginal locations such as developing peat bogs (Whitehouse, 1993). Several of the non-British species are also associated with fire damaged woodland, particularly *Betula* and coniferous woodland.

These investigations led to two PhD research projects focusing on both Thorne and Hatfield Moors. Boswijk (1998) undertook dendrochronological analyses of *Pinus* and *Quercus* remains from both Moors. The second project is presented in this thesis. The aim of the doctoral project was to examine a series of palaeoentomological successions across the Humberhead Levels, and in particular to elucidate the development of Hatfield Moors and its associated deposits, which had been little studied prior to the research.

The specific questions which this research addresses are:

- What is the nature of the burnt fossil forest on Hatfield Moors and the significance of fire within these deposits?
- How can fossil insect analysis elucidate mire genesis and initiation at Hatfield Moors? How does this differ across different areas of the Moors?
- Taking a long temporal perspective, how does Hatfield Moors differ and compare with Thorne Moors?

- Are there any anthropogenic signals within the faunas and how do these compare with other palaeoecological evidence?

- On Thorne Moors, there are remains of both *Quercus* and *Pinus* macrofossils, with *Quercus* generally pre-dating *Pinus*. What is the nature of the transition between *Quercus*- dominated to largely *Pinus/Betula*-dominated forest?

- How does the palaeoentomological evidence from Thorne and Hatfield Moors compare within a regional context, particularly with sites located within the floodplains?

The examination of these questions has provided information to:

1. Elucidate, from an entomofaunal perspective, the transition from forest to ombrotrophic mire preserved within the peats of Thorne and Hatfield Moors; the characteristics of these basal forests and the effects of environmental changes upon the composition of their insect fauna; examine any potential implications for the regeneration of cut-over peat bogs.

2. Assess the relative impact of fire, climate change and anthropogenic activity on the various elements of the British entomofauna.

3. Clarify the development of the British entomofauna, and the associated timing of changes.

4. Assess the implications for conservation in the light of the palaeoecological record. Palaeoentomological studies offer the opportunity to study woodland and mire insect communities on a long-term basis, over the evolution of the peatland. This temporal perspective provides valuable information to conservation of a variety of habitats.

Structure of the thesis

Chapter 1 provides background information about the Humberhead Levels and its important peatlands. Chapter 2 summarises all the previous palaeoecological and archaeological work carried out in the Humberhead Levels. This is followed by a review of palaeoentomology (Chapter 3). A summary of fieldwork carried out on Hatfield Moors to examine the distribution of the fossil woodland and record any information relating to mire initiation and development is presented in Chapter 4, together with details of sampling sites and stratigraphic details of all sites examined. Chapter 5 discusses the analysis of the insect material, including details of a new methodological approach and the first application of correspondence analysis on insect assemblages. Five chapters present and discuss results from Hatfield Moors (Chapters 6 and 7), Thorne Moors (Chapter 8), the correspondence analysis of the mire deposits (Chapter 9) and results from Hayfield Lodge Farm (Rossington), and Misterton Carr (Chapter 10). Chapters 11 and 12 attempt to examine some of the wider issues highlighted by the study of the insect faunas, including wetland development in the Humberhead Levels and the importance of fire events within forest mires (Chapter 11) and the biogeographic and climatic considerations of the faunas studied (Chapter 12). The conclusion attempts to highlight some of the issues concerning the conservation of insects and their associated habitats.

Nomenclature and conventions

Plant nomenclature follows Stace (1991); Coleoptera follows Kloet and Hincks (1977) and Lucht (1987).

Many of the insects discussed in this thesis are included in the Nature Conservancy Council's *British Red Data Books: 2, Insects* (Shirt, 1987). This is a comprehensive statement on the status of most threatened insects in Great Britain. The Book contains three major categories based upon degrees of threat "Red Data Book" 1, 2 and 3 (RDB classifications). In addition, there is a further classification of Notable species (Notable A and Notable B) (Hyman, 1992, 1994). An explanation of the classification system is given in Appendix A. Where appropriate, a comment of species' status has been made in the text, with reference to this classification system.

Radiocarbon dating calibration conventions and other dating

Radiocarbon dates have been calibrated using *Oxcal* v.2.18 (Stuiver and Reimer, 1993). Calibrated dates are denoted by a date range, shown as cal BC/AD, with details of the uncalibrated radiocarbon date, including lab number. Error limits have been calculated to 2 σ spans (95% level of confidence). Estimated radiocarbon years, used particularly for events during the latter part of the Devensian and early part of the Holocene are reported as uncalibrated radiocarbon years ("uncal BP"). Dendrochronological dates are also utilised (Boswijk, 1998). In this case, precise dates are reported and are not followed with radiocarbon details.

CHAPTER I: BACKGROUND TO THE HUMBERHEAD LEVELS.

1.1 The Humberhead Levels

The Humberhead Levels are delineated to the north by the river Ouse, east by the Trent, west by the dipslope of the Magnesian Limestone and south by the Sherwood Sandstone ridge from Bawtry to Gringley (Figure 1.1). The Isle of Axholme is a raised Mercia Mudstone outcrop situated to the east of the Levels and surrounded by the rivers Torne, Idle, Don and Trent and their associated floodplains. The flat-topped hills of this area rise to just over 40 m OD at Haxey. Crowle Hill, separated from the Isle by a strip of low-lying land, marks the northern extent of the mudstone ridge. These low hills are the main areas of higher ground in the Levels.

The raised mires of Thorne and Hatfield Moors lie to the north and south-west of the Isle. There are the two largest surviving examples of ombrotrophic lowland raised mire in eastern England (Rogers and Bellamy, 1972; Bain, 1992), which together with Haxey and Epworth Turbaries, consist of the remnants of what was once an extensive complex of raised mires, heathland, fen, carr woodland and wetlands. Since the seventeenth century the area has been drained and the remaining peatlands have been extensively cut-over for peat. Some indication of the pre-drainage landscape is provided by the "Traditional Map" of 1626 (Figure 1.2).

1.2 The Humberhead Peatlands

The Humberhead Peatlands are nationally and internationally important for their wildlife, containing 5% of the lowland raised mire resource in Britain; this is one of this country's rarest and most threatened habitats (Bain, 1992). The Moors are notified as Sites of Special Scientific Interest (SSSIs), proposed as Special Protection Areas (SPAs) under the European Birds Directive and qualify as Wetlands of International Importance under the terms of the Ramsar Convention (Kohler, 1997).

The Humberhead Peatlands are a meeting place of northern and southern species; a remarkably large number of plants and animals attain their distributional range limit at this point (Heaver and Eversham, 1991), resulting in a unique species mix. These raised mires are rather different from other lowland raised mires in Britain and unique as an ecosystem type: "*The two Moors can be considered the only truly Continental raised mires in Britain with stronger affinities with the Baltic lowlands*"(Heaver and

Eversham, 1991, 76). The Moors are perhaps better seen as sole examples of a now largely non-British biotope, rather than as damaged and impoverished "Atlantic" mires such as those which occur in western and upland Britain (Eversham *et al.*, 1995; Eversham, 1997b).

The Moors are important sites for palaeoenvironmental research (*cf.* Erdtman, 1928; Smith, 1958a; Buckland and Kenward, 1973; Buckland, 1979; Smith, 1985; Roper, 1993, 1996; Whitehouse, 1993, 1997a,b; Dinnin, 1994, 1997c) and are notable as having developed in an area of low rainfall, warm temperature and high evapotranspiration potential (510 mm/yr). Continued drainage for industrial extraction and agricultural purposes, as well as declining ground water levels has ensured a lowering of the bog water table. The concurrent degradation of the peat layers make the case for palaeoenvironmental research ever more urgent.

1.3 Location and Topography of Thorne and Hatfield Moors

Thorne Moors are located in the northernmost area of the Levels (NGR SE 7316), with Hatfield Moors 8 km to the southwest (NGR SE 7006). Sandy levées and the bed of a former branch of the river Don, which once flowed east to the river Trent (Gaunt, 1975), separate the two Moors. The Idle originally formed the eastern boundary of Hatfield Moors until it was diverted east to the Trent during the early seventeenth century (Limbert, 1978). Each Moor comprises several smaller areas, their names reflecting their status as former parish turbaries. Hatfield Moors comprises Stainforth Moor, Hatfield Moor, Fishlake Poor Piece and Lindholme; Thorne Moors comprises Thorne Waste, Crowle Moor, Goole Moor, Rawcliffe Moor, Snaith and Cowick Moors. Much of the area was incorporated within an area known in the past as "Inclesmoor" (Beresford, 1986) and was also part of the royal chase of Hatfield. This was the largest chase in England, containing more than 180,000 hectares and extending as far south as Bawtry, where it adjoined Sherwood Forest (Miller, 1804, 299).

The present surface of the Moors lies between 2 and 6 m. OD., below the natural high tide level of the surrounding rivers. The current surface topography is an artefact of peat cutting and varies by about 3 m across the Moors. Hatfield Moors has a central area, Lindholme Island, *c.* 24 hectares in extent, which rises to *c.* 4 m OD above the peat bog (Gaunt, 1994). There are also topographic low points across the Moors. The "Crowle Depression" reaches a low point of about -1.00 m OD beneath Crowle Moor and is thought to be an abandoned channel of the Don (Smith, 1985; Dinnin, 1997c). On

Hatfield Moors there are similar low points in the areas of New Moor south and New Porters Drain (Dinnin, 1997c), to the south-east.

Gaunt (1987) has estimated that about 50% of the original area of Thorne Moors has disappeared under warp since 1800. Warping is an improvement/reclamation process which consists of artificially depositing silt and clay ("warp") over pre-existing ground to improve its agricultural potential (Gaunt, 1987). On Hatfield Moors, only a limited area to the east, adjacent to the former river Idle, has been warped over, but peat has been stripped from large areas to the south and west. Heathwaite (1994) suggests that the peat deposits on Thorne Moors' were once originally up to 8 m deep, although historical sources suggest peat depths ranged between 4 - 6 m. Casson (1826, 1987 reprint, 117) suggested that the bog was *c.* 6 m deep in some places and Stovin (1730) recorded depths of up to 4.5 m in places on Hatfield Moors. In 1958 (a), A.G. Smith recorded thicknesses of up to 3.5 m in the south-eastern section of Hatfield Moors. Today, the peat is not much more than 1-1.5 m in depth in many areas, according to the author's own survey work, although areas of Rawcliffe Moors contain up to 5.4 m of peat (Dinnin, 1997c). As Smart (1983) pointed out, even where no peat cutting has taken place, there has been a reduction in peat depth due to drainage.

1.4 Floodplains of the Humberhead Levels

The raised mires of the Humberhead Levels are surrounded by the floodplains of the rivers Torne, Idle, Don and Went. Before drainage in the 17th century, the rivers weaved frequently-changing courses north-eastwards to the lower Trent and Ouse (Buckland and Dolby, 1973) and supported vast expanses of wetlands (Figure 1.2). Some of the rivers split into two or more courses (e.g. the Don), widening in places to form a series of meres (e.g. Thorne Mere) (Dinnin, 1997a). Associated with the river floodplains are deep peat deposits (Dinnin, 1997d).

Hayfield Lodge Farm, Rossington Bridge, near Doncaster, is located *c.* 10 km south of Hatfield Moors and is situated on the River Torne floodplain. Eastwards, the river drains the dislope of the Upper Magnesian Limestone and river occupies a relatively broad shallow valley, but as the river cuts through the Rossington Ridge, the valley narrows to less than 300 m (Dinnin, 1997d). Down-stream, the river occupies a relatively narrow floodplain which is flanked by extensive Holocene river terrace deposits (Dinnin, 1997d). Prior to canalisation, the Torne joined the Idle, flowing north to meet the Old Don north of Sandtoft (Dinnin, 1997d), until it eventually joined the Trent. The area around Rossington formed part of Potteric Carr, which extended from south Doncaster to Rossington and northwards to Hatfield Moors. The area around Rossington was, in 1761, regarded as being the last remaining fragment of virgin bog which had covered the entire carr (Skidmore *et al.*, 1980, 22). By 1804, however, the Torne was canalised and this process destroyed the vast areas of wetlands associated with the river (Skidmore *et al.*, 1980).

Misterton Carr, on the floodplain of the River Idle, is *c.* 14 km south-east of Hatfield Moors. The Idle is also flanked by extensive peat deposits, although on Misterton Carr the peat is generally less than 1.00 metre thick (Gaunt, 1994), but reaching 2.20 m in places (see Chapter 10). The floodplain in the proximity of Misterton is poorly defined and more than a kilometre wide. The river is artificially constrained today and improved drainage in the 1970s has turned the whole area into arable land (Dinnin, 1997d).

1.5 Geology and Geomorphology

The geology of the area has been described in detail by Gaunt (1981, 1987, 1994). The bedrock geology consists of rocks of Triassic age, with the rockhead at -5 to -15 m OD (Gaunt, 1994). The Sherwood Sandstone Group (formerly Bunter Sandstone) underlies almost the whole of the area, although the Mercia Mudstone Group (formerly Keuper Marl) occurs in the eastern fringe of the Moors and outcrops at Crowle and the Isle of Axholme. These rocks are overlain by gravels, sands, silts, clays, peat and alluvium (Figure 1.3).

During the early part of the Quaternary, the denudation régime which had persisted during the Tertiary probably continued. In at least one major glaciation, of pre-Ipswichian date, a thick ice sheet extended across the area. Subglacial erosion cut deep channels into the bedrock, subsequently these were infilled with deposits ranging from laminated clay to gravel. During deglaciation, till and fluvioglacial sands and gravels were deposited in the district. In the early part of the Ipswichian Interglacial, sea levels remained well below their present levels and rivers incised courses to at least -13 m. below OD in places, probably due to glacioeustatic effects. With the subsequent rise in sea levels to just above OD, rivers eventually deposited spreads of sand and gravel (Gaunt, 1994).

During the early and middle Devensian Glacial Stage, sea levels fell to more than - 20 m. below OD. Rivers transversing the district incised wide valleys down towards the Humber Gap. Both cryoturbation structures and ventifracts were formed during this prolonged incision and denudation phase (Gaunt, 1981, 1994). There is little evidence for sediment deposition until Late Devensian ice blocked the Humber Gap from the North Sea (Gaunt, 1994), creating a pro-glacial lake, Lake Humber *c.* 21,000-18,000 radiocarbon years ago (Gaunt et *al.*, 1971; Gaunt *et al.*, 1974). Ice flowing down the Vale of York entered the northeastern areas of the district, sometime before 12,400 BP (Gaunt, 1976, 1987), after which the ice sheet retreated north to the Vale of York and stabilised at Escrick (Gaunt, 1987). The glacial sand and gravel outcropping at Thorne, Tudworth Hall, Lindholme and Wroot, just south of Hatfield Moors, are thought to have been laid down by ice as it surged transiently into Lake Humber (Gaunt, 1994, 114).

Lake Humber rose initially to above 30 m OD, before becoming established at *c.* 9 m above OD (Gaunt, 1994), depositing thick laminated silt and clays. Lake Humber eventually disappeared, apparently as a result of sediment infilling (Gaunt, 1981, 1994). A palaeosol which developed on the lake deposits at West Moor, Armthorpe, north-east of Doncaster, dated to *ca.* 11,100 ± 200 uncal BP (N-810) provides a minimum age for the final disappearance of the lake (Gaunt et *al.*, 1971). This date has recently been re-calibrated to 13,010 ± 200 cal years BP (Bateman, 1995, 797).

After Lake Humber disappeared, rivers initiated courses across the abandoned plain, depositing levées adjacent to their braided channels (Gaunt, 1981). These deposits are generally not more than 2.5 m thick, forming low ridges and mounds in a linear distribution, running eastwards across the northern part of Hatfield Chase (Gaunt, 1994) and together with the course of the old river Don, separate Thorne and Hatfield Moors.

During the late Devensian, extensive deposits of wind blown sand accumulated (Gaunt, 1981; 1994). Similar aeolian sand deposits ("coversands") have been found elsewhere in the region, for example at Messingham, 6 km. south of Scunthorpe, where a peat deposit sealed beneath 2 m of wind-blown sand has been dated to 10,280 ± 120 uncal BP (BIRM-349); a peaty lens within the overlying sands dated to 10,550 ± 250 uncal BP (BIRM-707), dating the deposits to the final phase of the last glaciation (Buckland, 1982). Extensive thermoluminescence and radiocarbon dating of the coversands from Conesby Quarry and Black Walk Nook, north Lincolnshire, indicate sand started to accumulate around 11,850 ± 960 years (TL date) and 12,480 ± 1,130 (TL date) years ago respectively (Bateman, 1995). This sand continued to accumulate through to the early Holocene, as the dates from the upper part of the sand deposit at Black Walk Nook of 10,780 ± 840 (TL date) years and 10,040 ± 790 (TL date) years from Conesby Quarry indicate (Bateman, *op. cit.*). Deposits of this blown sand cover large areas of Hatfield Moors, where sand thickness reaches 4.6 m. in places (Gaunt, 1994). The deposits form outcrops protruding through the peat and can be recognised as the tops of dunes. This is a rather unusual feature when compared to other aeolian deposits in the area, where the sand is rarely in the form of fossil dune fields except where it has been reworked during the Holocene (Bateman, 1995). These sands also protrude through the peat in the vicinity of Misterton Carr (Buckland and Dolby, 1973).

At the beginning of the Holocene and possibly during the Younger Dryas Stadial, the glacial deposits blocking the Humber Gap were breached. The rivers again deeply incised their courses down to nearly -20 m below OD in response to the continuing low sea levels (Gaunt, 1994). By c. 7,000 uncal BP sea levels in the Humber estuary had risen to about -9 m O.D. (Gaunt and Tooley, 1974; Dinnin and Lillie, 1995). Sea levels continued to rise rapidly between 7,000 and 6,000 years ago and river channel aggradation occurred. With the rising watertable, much of the low-lying river floodplains and clay soils became increasingly waterlogged and peat deposits formed in the more low-lying areas (Gaunt, 1994), mainly on Thorne Moors and from Hatfield Moors southwards to Misterton Carr.

Peat growth on Thorne Moors had began *c.* 3370-3100 cal BC (4545 ± 75 BP, CAR-211) and on Hatfield Moors *c.* 3040-2890 cal BC (4335 ± 75 BP, CAR-254) (Smith, 1985). These are minimum ages for peat initiation. Dates from elsewhere in the Levels would appear to corroborate wetland initiation at about 3500-3300 cal BC. Dates of 3000-2620 cal BC (4230 ± 100 BP, BIRM-358) from the base of a channel of the river Don at Thorne Waterside, 2920-2660 cal BC (4230 ± 70 BP, CAR-309) from the base of the Don at Crowle (Crowle "Depression") and 3300-2700 cal BC (4330 ± 120 BP, BIRM-359) from the base of the Idle at Misterton (Buckland and Dolby, 1973) all suggest floodplain peat development *c.* 3300-3000 cal BC. These dates do not necessarily reflect the onset of channel aggradation. New evidence from the Humber Wetlands survey suggest earlier peat initiation in floodplains of the Levels (e.g. Hampole Beck at Sutton Common, dated to *c.* 5320-3990 cal BC [*c.* 6300-5200 uncal BP]) (Lillie, 1997a). Mather (1991) suggested that peat deposition in the Torne at Rossington Bridge began *c.* 6000-5500 cal BC (*c.* 8000 uncal BP). These latter two dates are based upon palynological evidence rather than radiocarbon dating.

By about *c.* 2000 cal BC (3500 uncal BP), sea-level was around OD and the river channels had been largely infilled; floodwaters spread beyond the channel confines, causing overbank alluviation (Buckland and Dolby, 1973; Samuels and Buckland, 1978; Gaunt, 1981; Buckland and Sadler, 1985), much of which has been assigned to the late Roman period. This increase in sedimentation has been attributed to changes in the hydrological regime due to altered land use. The influence of rising water levels continued to be felt throughout most of the historical period.

1.6 Human alterations to the landscape: drainage and reclamation

Accounts of the drainage history of the Humberhead Levels are given by Stovin, (1730), Miller (1804), Peck (1813), Stonehouse (1838), Dunston (1909) Cory (1985) and have been recently summarised by Dinnin (1997a).

Prior to drainage, much of the area consisted of large areas of fen and carr, as well as the raised mires of Thorne and Hatfield. The first major drainage work involved the course of the River Don, north of Thorne, which was turned into an artificial waterway (Turnbridge Dike) (Gaunt 1975). Attempts have been made, on palynological grounds, to argue that this branch is mid-Holocene, but the arguments are not convincing (Lillie, 1997a, 56). Gaunt (1975), based on cartographic and documentary evidence, suggests that it was probably constructed before *c.* 1343 AD (Gaunt, 1975; Dinnin, 1997a), during either the Roman period or after the Norman conquest (Gaunt, 1975). Bykers Dike (or By Carrs Dike) and Hekdike are also thought to be medieval or earlier artificial channels (Dinnin, 1997a). Korthals-Altes (1925, 2) has suggested that Bykers Dike is Roman in date. Jones (1995) also argues that Bykers and Turnbridge Dikes may have been constructed for navigational purposes during the Roman period, and their lack of maintenance after this time may have exacerbated drainage problems in the area.

In 1374, Hatfield Chase became a royal property when it passed from the Earls of Surrey to the House of York, although it did not become subject to Forest Law until 1460 (Cory, 1985). Much of the Chase remained a swampy wilderness in which commoners had been granted fishing, fowling, timber and turbary rights by the Mowbrays and Lacys (Gaunt, 1987). Accounts suggest that into the nineteenth century many poor families in the vicinity of Hatfield supported themselves cutting peat (Miller, 1804, 10). These areas provided important means of livelihood for the people of the Humberhead Levels (Thirsk, 1953). Hemp and flax were grown in the area, leading to a flourishing sack- and canvas-making industry on the Isle of Axholme. The dikes and rivers were important means of transport. The commons were very important as they provided additional revenue to villages which were able to take in stock for grazing over the summer. With the onset of drainage, the commons were reduced to between a half and a third of their former size (Thirsk, 1953).

A Commission appointed by King James I to report on the possibility of draining the area concluded in 1622 that it was impossible to drain or improve the land (Ministry Of Agriculture and Fisheries Report, 1928). However, by 1625, Charles I had signed an agreement with Cornelius Vermuyden, a Dutchman, granting him permission to drain Hatfield Chase. Vermuyden started drainage works in 1626 and his work largely consisted of diverting the Idle, Torne and Don and other existing watercourses, so that they would discharge continuously into the Trent and Ouse (Cory, 1985). Both Thorne and Hatfield Moors remained unimproved by the drainage schemes, although Josias Arelebout's map of Hatfield Chase, surveyed in 1639, appears to show a "ring" drain around Hatfield Moors (Limbert, 1985).

The drainage works proved defective and some areas which previously had never flooded now began to flood. A series of improvements was carried out resulting in the construction of the Dutch river, completed in 1635-36. Despite these drainage activities, Hatfield Chase, from the edge of Doncaster to the Isle of Axholme, was often submerged during winter (Skidmore *et al.*, 1980). At Potteric Carr, near Doncaster, drainage was not completed until 1777 (*ibid.*), and waterlogging was still a major problem in the early nineteenth century (Miller, 1804).

“Warping” is first recorded as being carried out near Rawcliffe in 1730-40, although the technique may be older (Gaunt, 1987). This practice is virtually unique to the southern part of the Vale of York and consists of artificially depositing silt and clay over pre-existing ground to improve its agricultural potential (Gaunt, 1987). Between 1800 and 1860 huge tracks of land were “warped” (*ibid.*). “Flood-warping” was carried out on a large scale. This practice utilised the substantial load of sediment carried by the local rivers and the reversal of flow at high tide. Areas to be warped were embanked and allowed to flood, via a warping drain channelled to the nearest river. At high tide sluice gates at the warping drain were opened, allowing sediment-rich water to flood the area. The water was then allowed to drain back into the river, leaving a rich sediment upon the fields. Up to 1 m of sediment could be deposited in one year and in many places warp exceeds 3.5 m in depth (Gaunt, 1987). “Cart warping” consisted of excavating alluvium, transporting it by cart and then dumping it upon the land in thicknesses of 15-25 cm (Gaunt, 1987). This was carried out on the north-eastern margin of Hatfield Moors. Warping is further discussed by Gaunt (1987) and Lillie (1997b).

1.7 Human alterations to the landscape: mineral extraction.

By the fourteenth century, hand "graving" (peat cutting by hand) had begun at Thorne and Hatfield Moors (Eversham, 1991), continuing until the early 1960s. Beresford (1986) provides an account of the grants given to religious houses and hospitals for turbary and grazing rights over parts of the area known as "Inclesmore", known to cover at least Thorne Waste and Goole Moors. A causeway marked on the six inch scale 1850s O.S. maps for Thorne Moors, linking Thorne and Crowle Moors (Limbert, 1987a), may have represented a medieval boundary marker linked to the turbary rights of religious houses (Limbert, 1987a and *pers. comm.*, 1997). Inclesmoor is shown on a map dating to *c.* 1410, (Plate 1.1) probably produced to illustrate land ownership of some economic importance. With clearance of woodland, peat turf had become more important as a source for domestic fuel, especially in towns and for those industrial processes which required heat, such as the work of potters, dyers, tile-makers and brewers (Beresford, 1986). The brickyards at Hull are known to have been using Inclesmore peat; the proximity of this source of fuel to the Cowick potteries suggests it is likely that these kilns were fired with peat as well as coal (Knowles, 1990, 370). In view of the considerable value attached to Inclesmore, it is probable that Hatfield Moors was exploited in much the same manner.

By the 1820s, peat cutting was having a major impact upon the Moors. From 1884, drainage was aided and augmented by the renewed interest in commercial peat extraction, following revival of the use of peat, particularly as animal litter (Limbert, 1987a; Eversham, 1991). On Hatfield Moors, commercial peat cutting began in 1888 (Eversham and Lynes, 1980). This extraction continued to increase in tonnage until *c.* 1910 when peat production was at its highest, after which the market declined with the arrival of the motor car. Fitzrandolph and Hay (1926) provide a picture of the peat industry on Crowle Moors around this time.

Planning permission for peat extraction was granted in 1950/51. In the 1960s, with the arrival of Fisons Ltd. on the Moors, mechanical cutting replaced hand graving. Initially, this technique affected the vegetation of the Moors in much the same way as hand-graving, but by 1980 the amount of vegetation in the cut-over areas was substantially reduced. Shortly after this, peat milling was introduced first onto Hatfield and then in 1985 to Thorne Moors. This method involves the wholesale stripping of large surfaces and the construction of shallow ditches (*c.* 1 - 1.5 m deep) to facilitate the rapid drying of the superficial layers. Modern peat milling tends to cover patches of about 200-400 hectares which are recut several times each summer. The distances between bare peat and the nearest plants and invertebrates may be between 500-2000 m. (Eversham, 1991), making re-colonisation of the disturbed landscape difficult. The requirement for a dry peat surface for milling has necessitated greater drainage of the Moors, resulting in seasonal desiccation of the adjacent wetlands (*ibid.*). By 1990, only about 10% of Hatfield Moors and 30% of Thorne Moors retained any vegetation cover (Ball, 1992). This destruction continues, despite the sites' SSSI status.

By the middle of the present century destruction of the Moors by drainage, commercial peat removal and land reclamation was causing a local naturalist of Thorne, William Bunting, considerable concern (Limbert, 1987b). However, the natural richness of the Moors had not entirely faded.

1.8 The nature of the raised mires of Thorne and Hatfield Moors

Several historical accounts (Peck, 1813; Hatfield, 1866; Casson, 1829; and historical summaries by Limbert, 1987a, b) provide a picture of the appearance of the Humberhead Levels and mires prior to large-scale drainage and peat extraction. The earliest description of the Humberhead Levels is by John Leland (1538); as Howes (1997, 22) comments, Leland provides a *"window onto what must have been a truly fabulous "everglades-like" landscape.."*:

"The quaters about Heatfeld be forest groundand though wood be scars there yet there is great plentie of red deere, that haunt the fennes and the great mores thereabout as to Axholm warde and Thurne village......The ground al about Thurne is other playn, more or fenne. From Thurne by water to the great lake caullid the Mere, almost a mile over, a mile or more. This mere is fulle of good fisch and foule" (Leland, in Smith (ed.), 1964, 37).

In the eighteenth and early nineteenth centuries, Thorne Moors' mire surface was still actively growing. In the mid nineteenth century, Hatfield (1866) recounts that when a William Harrison first went to live at Thorne, Crowle Church could be seen from his house. However, within a decade, there had been such a rapid rise of the surface of the mire that the church had become obscured from view. Woodruffe-Peacock (1920-21) commented that as late as 1874 Thorne Moors was *"a shaking bog"* which trembled in waves when jumped upon. Woodruffe-Peacock (1920-21) describes the dome of Thorne Moors as once rising 7.5-10.5 m above the surrounding plain, with a seasonal fluctuation, of about 2 m. (Limbert, 1987a). This variation in the height of the domed peat surface between seasons and wet and dry years was destroyed with drainage.

During the early part of the nineteenth century, between Haxey (Isle of Axholme) and Bearswood-Green (near Hatfield), the landscape was akin to a continuous lake and transport was undertaken by boat (Tomlinson, 1882). Hatfield (1866, 134) noted that around Lindholme the vegetation on the Moor was too dense to allow the passage of boats but was too moist and deep to be safely crossed on foot or on horseback, except in times of frost or drought.

The six inch scale O.S. map for Thorne Moors published in the 1850s showed many scattered pools of more or less open water, known locally as wells (Limbert, 1987a, 36); cutting of deep drains eventually destroyed such bog features. Casson (1829), referred to pools on Thorne Moors, which were *"..large ponds or pits of dark coloured water, perfectly free from weeds and aquatic plants, which are places of resort for the wild fowl that frequent the moor"* (1987 reprint, 117). Hatfield (1866, 152) comments on these pits and noted how they *"..were deemed by the superstitious to be bottomless.."*. The pools were certainly dangerous, as moss encompassed the margins, obscuring the water, *"..the floating mass of moss and other fibrous vegetation have accumulated to a considerable thickness, extending partly across the water and in several instances, entirely over it..."* (Hatfield, 1866, 153). Similar pools probably would have been present on Hatfield Moors, although only one is evident on the six inch 1853 scale O.S. map (possibly artificial). Pool systems are characteristic of mires, remaining a feature of the bog landscape for a considerable time, possibly many centuries (Casparie, 1972; Aaby, 1976; Hulme, 1986).

Today, the hydrology of the Moors is constantly modified due to peat cutting, which requires drainage of large areas through a network of shallow ditches. The effect of the drainage is to maintain a hydraulic gradient towards the edges of the Moors, thus lowering the watertable in the peat. Both sites suffer from lateral and vertical substrate seepage (Heathwaite, 1995). The large amounts of fossil trees create a barrier and channels along which water can flow, seeping out of the bog (Heathwaite, 1995).

Pumped land drainage systems in the surrounding areas also affect water levels, maintaining winter levels in the range of -0.2 to -0.5 m OD. As the thickness of the peat cover is diminished by cutting and drains deepened, the water holding capacity is reduced accordingly. During the last twenty years ground water levels have fallen significantly in the Doncaster area (Kohler, 1997), and after three years of below average rainfall, the 0 m OD contour in the water table has shifted several kilometres to the east.

1.9 Modern flora and fauna

Areas within the central part of Thorne Moors are still capable of supporting elements of raised mire vegetation. Peat generation still takes place through the active growth of *Sphagnum* mosses. Hatfield Moors is notably drier than Thorne Moors, due to its underlying porous mineral substrate. The current vegetation of the Moors is influenced by their underlying geology as well as by drainage and peat-cutting activities. The two areas therefore have a significantly different wetland status.

Two aspects are of particular relevance to the vegetation of the area: warping around Thorne Moors and the sand and gravel deposits beneath Hatfield Moors. A few areas on Thorne Moors (Will Pits) were warped over, but were never utilised for cultivation. Today, *Salix* woodland, fen grassland and reeds have developed. Elsewhere, saline outflow from Moorends Colliery has allowed an area of saltmarsh to develop (Eversham, 1997a). On the southern side of Thorne Moors, on the National Nature Reserve, areas of long abandoned flooded peat cuttings retain species characteristic of ombrotrophic mire. Plant species include *Andromeda polifolia*, *Vaccinium oxycoccus*, *Myrica gale*, *Eriophorum augustifolium* and various *Sphagnum* spp. Drier cuttings and raised baulks are dominated by wet and dry heath species (e.g. *Calluna vulgaris*, *Erica tetralix* and *Betula pubescens*) (Eversham, 1997a). On the north side of the Moor large-scale peat milling continues.

Hatfield Moor is bounded by arable farmland and large areas consist of unvegetated peat. Elsewhere, *Betula pendula* dominates, together with species of wet and dry heath such as *Calluna vulgaris*, *Molinia caerulea*, *Erica tetralix* and *Betula* scrub. In wetter areas there are *Eriophorum* species and *Sphagnum* is present in places, with *Juncus* spp. and *Phragmites australis*. Elsewhere, there are also *Myrica gale* and *Andromeda polifolia* (Eversham and Lynes, 1980). Along the margins of the Moor are semi-mature *Betula pubescens* stands, with scattered areas of *Pinus sylvestris* and small areas of *Salix*. The southwestern section of Hatfield Moors (Poor Piece) contains relict mire plant and insect communities. There is scrub/woodland, where *Quercus petraea/robur* is frequent, often with scattered *Acer pseudoplatanus*,, *Fagus sylvatica*, *Fraxinus excelsior*, *Betula pubescens*, *Alnus glutinosa* and *Populus tremulens*. The understorey is dominated by mature *Calluna vulgaris* and there are large patches of mature *Erica tetralix* and *Andromeda polifolia* (Heaver and Eversham, 1991). On the western edge of Hatfield Moors the shallow peat overlies sand. This has affected the local vegetation and faunal types which have been described as having similarities to the heathlands of the East Anglian Breckland, coastal sand-dunes as well as raised mire (Heaver and

Evesham, 1991). Lindholme Island supports calcareous and acid grassland as well as woodland, mainly *Betula*, mature *Quercus* and some *Pinus sylvestris (*Eversham, 1997b). The site is considered worthy of SSSI status (*ibid.*).

Today, large areas of Thorne and Hatfield Moors are undergoing managed re-wetting, in an attempt to regenerate the mire. The aim is to re-create vegetation which is "capable of peat formation", taken to include *Sphagnum* moss species, *Eriophorum augustifolium* and *Juncus effusus* (Tantram and Dargie, 1995).

Among the notable animals which inhabit the Moors, the nightjars, *Caprimulgus europaeus,* a rare and vulnerable species, is a feature of the regenerating birch scrub; the Moors hold more than 1% of the national population (Bain, 1992). The ornithology of both Moors has been extensively researched (*cf.* Limbert, 1977, 1990, 1991, 1992, Limbert *et al.*, 1986; Bain, 1992; Roworth, 1997).

Extensive historical research of botanical records from the Moors by Martin Limbert in particular (1987a,b), has highlighted the diversity of plants and animals living or which formerly lived on the Moors. The first located reference to the flora is by Leland who visited Hatfield, Epworth manor and the Isle of Axholme in 1538, *"The fenny part of Axholme berith much gale, a low frutex swete in burning..."* (Leland, in Smith (ed.), 1964, 38). George Stovin commented on Thorne Moors in 1730 that *"It affords plenty of cranberries and an odoreferous shrub called Gale; some call it Sweet willow, or Dutch myrtle"* (Stovin, 1730, 1905 reprint, 37).

Thorne Moors did not become botanically important until 1831, when *Scheuchzeria palustris,* one of Britain's rarest plants, was discovered (Hatfield, 1866). This species also lived on Hatfield Moors. However, in about 1860 warping of Thorne Moors was proposed, under the Thorne Moors Improvement Company. Nine years later, Casson (1869) noted that the surviving peat moorland was in a transitional state, where plants such as *Potamogeton oblongata, Utricularia minor* and *Scheuchzeria palustris* could no longer be found on the Moors (Limbert, 1987b). Casson described the different species of *Sphagnum* moss covering Thorne Moors: *"the margins of the ponds...are beautifully fringed with variously coloured moss, in greens, in pinks and up to dark maroon or brown"* (Casson, 1874, 136-7). Despite the growing drainage system, effective drying of the peat was spatially fragmented, reversible and gradual in its results; species such as *Scheuchzeria* were able to persist at least until 1880 (Davis and Lees, 1878, 377), although by 1905 *Scheuchzeria* seems to have disappeared (Bunker, 1905). Drainage probably accounts for the loss of *Narthecium ossifragum, Drosera anglica, Hypericum* *eloides* and *Carex limosa* (Smart *et al.*, 1986). Stratigraphic work indicates the former abundance of several species of *Sphagnum* moss, including *S. imbricatum* and *S. magellanicum*, which no longer occur (Smith, 1985; Smart *et al.*, 1986). The important mire-building *S. imbricatum* probably disappeared from Thorne Moors during the twelfth - fourteenth centuries, possibly as a result of increased wetness, leading to competition with *S. magellanicum* (Smith, 1985; Stoneman *et al.*, 1993). The latter also became extinct from the two sites sometime before the 1920s (Smith, 1985; Smart *et al.*, 1986).

Far less work on the historical ecology of Hatfield Moors has been undertaken, with the exception of Eversham and Lynes (1983) and Anon (1888). Many characteristic species of raised mire have been lost or have become severely restricted in their distribution on Hatfield Moors. A record from 1966 provides indication of what the site must have looked like. *"Drier even then than Thorne Moor but similarly a superb, vast-wilderness-like place, it differed from Thorne Moors on its clumps of Scots Pine, its beds of Sweet Gale and the old oaks on the low moraine of Lindholme. It had a truly medieval appearance and a character of its own... "* (Skidmore, 1992, 67).

1.10 Invertebrates of the Moors

Thorne and Hatfield Moors show an exceptional diversity of invertebrate species. Several extensive surveys have been undertaken, principally by Skidmore *et al.* (1985), Heaver and Eversham (1991) and Skidmore (1997; *in press*). The recorded insect fauna of both Moors exceeds 5,000 species (almost 25% of the British fauna) (Eversham, 1997b), with over 30 RDB Species (Shirt, 1987) and over 250 nationally-scarce species, including six known from no other sites in Britain (Eversham, 1997b). Three of the latter were new to Britain in 1992 (Skidmore, 1992; Eversham, 1997b).

Thorne Moors, in terms of its invertebrate fauna, has been recorded as the richest peatland site in Britain, containing the fourth largest assemblage of rare species of any site (Ball, 1992). Hatfield is in the top ten of such sites (Heaver and Eversham, 1991; Key, 1991) and has been far less thoroughly surveyed than Thorne Moors (Skidmore, 1997). The Moors are notable as the only British localities for the RDB1 ground beetle *Bembidion humerale* and the RDB1 pill beetle *Curimopsis nigrita*, both of which are rare throughout Europe. This latter species has been recovered as a fossil in deposits *c.* 3,000-3,500 years old (Buckland and Johnson, 1983; Whitehouse, 1993). The Moors are also the only find spots for the RDB2 Muscid *Phaonia jaroschewskii* Schnabl. (Diptera). All three species have a distribution centred upon the Baltic, with most records coming from Germany and Poland (Heaver and Eversham, 1991, 43). Indeed, the recorded European distribution of the most important members of the insect fauna at the two sites place them as western outliers of a bog type otherwise typical of sites in Poland, Germany and the Baltic states (Evesham, 1997b).

Results of the surveys indicate the differing nature of the two Moors. Thorne Moors has richer peatland, fenland and estuarine communities (Skidmore *et al.* 1985; Key, 1988), whereas Hatfield has richer woodland, sandy/calcareous grassland and sandy heath faunas (Skidmore, 1997). The Hatfield material reflect a disproportionate number of species which are not found in any other location studied, emphasising the overall atypicality of Hatfield as a peatland and reflecting its affinity to heathland (Heaver and Eversham, 1991). Sandy heathlands in the region have suffered greater losses than peat-based habitats and the surviving sandy heathland elements at Hatfield take on a particular importance when assessing the Moors' regional conservation value (Heaver and Eversham, 1991; Skidmore, 1997). Changes in invertebrate species also suggest the general lowering of the watertable (Eversham and Skidmore, 1991; Skidmore, 1992), with unequivocal evidence for the contraction or disappearance of sensitive species associated with the wettest habitats (Eversham and Skidmore, 1991, 28; Skidmore, 1992) and associated increases in dry heathland components.

Many species of plants and insect which occur plentifully at Thorne and Hatfield are rarely encountered elsewhere (Heaver and Eversham, 1991, 77). It appears that genetic isolation of several thousand years has produced forms of the Large Heath Butterfly (*Coenonympha tullia* Müller) which differ from populations elsewhere in Britain (*ibid.*). This also extends to some of the plant species, notably the populations of *Pinus sylvestris* on Lindholme Island and its environs (Eversham, 1997b). This island appears to hold elements of a fauna which has been buffered from the surrounding land by the barrier of the raised mire of Hatfield Moors and supports populations of great biogeographic and genetic interest. The invertebrate data from both Moors underline and re-enforce their importance, at regional, national and international scales (see Chapters 6, 7 and 8).

CHAPTER II: PREVIOUS PALAEOENVIRONMENTAL RESEARCH IN THE HUMBERHEAD LEVELS

2.1 Early palaeoenvironmental research

The palaeoenvironmental importance of this region has been recognised for a considerable time. As early as the seventeenth century, antiquarians and historians recognised the remarkable preservation of trees, human bodies and a wide variety of archaeological remains within the peats (e.g. Dugdale, 1662; De la Pryme, 1701; Stovin, 1730, in Jackson 1882). De la Pryme (1701) wrote to the *Royal Society* concerning the numerous trees buried within Hatfield Chase,

"In the Soil of all... are found infinate Millions of the Roots and Bodies of Trees of all bignesses great and little, ... It is very observable and manifestly evident, that many of those trees of all sorts have been burnt, but especially the pitch of fir trees, some quite through and *some all on one side; some have been found chopped and squared, some bored through, others half split with large wooden wedges and stones in them... Hazel Nuts and Acorns have frequently been found at the bottom of the Soil of the Levels and Moors and Firr or Pitch Tree Apples or Cones in great quantities."*

De la Pryme concluded, "*That ye Romans cut down and destroyed ye vast forest, that grew upon ye Levels of Hatfield Chase...*"

Thorne Moors attracted the interests of several early palynologists. Erdtman (1928) carried out pollen analysis from the Moors and concluded that peat formation began during the late Atlantic period (Pollen Zone VIIa, *c.* 7000-5000 uncal BP). Pigott (1956, 85) reached a similar conclusion and suggested that "*the alluvium is probably the product of the flooding of the region during the late Neolithic transgression.*" M. Pigott (cited in Pigott 1956) recorded *Scheuchzeria* rhizomes and *Fagus* pollen around the Zone VIIb-VIII transition with records of cereal and weed pollen, suggesting cultivation at the beginning of the Bronze Age.

The first major work undertaken on Hatfield Moors was carried out by A.G. Smith (1958a), who considered that peat began to form in Pollen Zone VIIa (*c.* 7000-5000 uncal BP). The absence of reedswamp peat at the base of the *Sphagnum* peat on Hatfield Moors led Smith to suggest that the raised mire peats developed in a manner analogous to blanket mire. Smith (*ibid.*) detected a poorly defined Neolithic "*Ulmus* decline" in the pollen record which was accompanied stratigraphically by a charcoal layer. Two other major forest clearance episodes were indicated, attributed to the Iron Age and Roman period. The latter was followed by a phase of forest regeneration. Smith also identified four "flooding horizons", comprising layers of unhumified *Sphagnum* and *Scheuchzeria* peat, suggesting episodes of increased wetness on the mire. The coincidence of post-Roman forest regeneration with one flooding horizon led Smith to postulate a loss of agricultural land during the post-Roman period. Turner (1962) subsequently radiocarbon-dated the flooding horizons on Hatfield Moors and produced pollen diagrams from Thorne Moors. These were used, in part, to argue that the observed decline in *Tilia* pollen (the "*Tilia* decline") was due to the effects of anthropogenic forest clearance; two such declines were identified, both being attributed to human clearance activities in the Bronze and Iron Ages.

2.2 The Bronze Age Thorne Moors trackway

In 1971, a Bronze Age trackway, radiocarbon-dated to 1390-1060 cal BC (2980 ± 110 BP, BIRM-337) was found during drainage ditch excavation on Thorne Moors. (Buckland, 1979). The structure was partially excavated and subject to a palaeoenvironmental investigation (Buckland and Kenward, 1973; Buckland, 1979). The split timber trackway was '*built from easily obtained and partially rotted trees...thrown into the mire, ... probably fairly open, if vegetated pools ... form[ing] an irregular surface*' (Buckland 1979, 55). The trackway was presumably built to provide a pathway across the growing mire, possibly connecting two areas of drier, higher ground. The northwest/southeast orientation of the trackway was aligned with the higher area on which Moorends Colliery now stands and a higher area of Lake Humber deposits, now concealed beneath the peat, possibly in the region of Medge Hall. The extent of the structure remains unknown and it is possible that it might have served some other function, for instance, as a hunting platform (Dinnin, 1997c).

2.3 Recent work

Following this work, B. Smith (1985) undertook what remains the most comprehensive investigation of peat stratigraphy, plant macrofossils and pollen from the two Moors. The work included 23 radiocarbon dates from Hatfield Moors and 54 from Thorne Moors, obtained from a series of peat profiles and borehole transects across the peatlands. Thorne Moors was the subject of the most intensive study, including pollen analysis of eight peat sections. Two sections were examined from Hatfield Moors. Smith (1985) used his results to construct regional pollen assemblage zones (termed

HHL/ in the following synthesis) for vegetation and landscape changes in the Humberhead Levels. The pollen zones represent a series of woodland clearance episodes dating from the Bronze Age through to the medieval period. Smith (1985) also used analysis of plant macrofossil content and degree of humification to identify a series of five recurrence surfaces which he attempted to correlate between Thorne and Hatfield Moors and with sites elsewhere in Britain and Europe. He tentatively linked these changes in mire surface wetness to phases of climatic deterioration, the influence of sea-level rises and autogenic vegetational processes.

Smith (1985) obtained radiocarbon dates of 2900-2660 cal BC (4180±70 BP, CAR-168) and 3090-2890 cal BC (4335±75 BP, CAR-254) for the onset of peat development on Hatfield Moors. He suggested that ombrotrophic mire developed rapidly following paludification, although initially *Alnus-Betula* woodland may have grown on parts of the mire surface. Radiocarbon dates from the basal peats on Thorne Moors suggest that development was time-transgressive, commencing earlier on the northern part of the peatland (Rawcliffe Moors), *c.* 3370-3100 cal BC (4545±75 BP, CAR-221), on the slightly higher area to the south (Thorne Waste) around 1420-1260 cal BC (3060±65 BP, CAR-180). Paludification led to the drowning and *in situ* preservation of the undisturbed forest that grew on the land surface. The plant macrofossil record from both peatlands indicate the progressive isolation of the mire surface from nutrient-charged water of the regional watertable, resulting in acidification. Thus raised mire on Thorne at least, developed from rheotrophic fen, via mesotrophic nutrient-poor fen, to ombrotrophic raised mire. The ombrotrophic raised mire and peripheral fens of Thorne and Hatfield Moors probably spread laterally until they were constrained by higher ground and the network of water courses that virtually encircle them.

Away from the Moors, palaeoenvironmental research has been more limited. Mather (1991) analysed an undated pollen sequence from a palaeochannel of the River Torne near Rossington, which spans the latter part of Pollen Zone VI to about the end of the Roman period (*c.* 5500 cal BC to 500-600 cal AD, *c.* 8000-1500 uncal BP). His palynological assemblage zones form the basis for the earlier part of the Holocene history of the Levels. Mid to late Holocene pollen and insect assemblages have been recovered from Misterton Carr and Thorne Waterside (Osborne, 1978; Buckland, 1979). An undated outline pollen diagram has been prepared from the peat sequence at Shirley Pool (Ward, 1988, in Dinnin, 1997b), suggesting a record which spans the latter part of the Holocene; the palaeoentomological potential of these deposits has been discussed by Dinnin (1992). The adjacent later prehistoric enclosures at Sutton Common have been examined for their pollen, plant macrofossil, fossil insects and waterlogged wood record (Boardman, 1997; Boardman and Charles, 1997; Brayshay, 1997; Parker Pearson, 1997a; Roper and Whitehouse, 1994, 1997; Taylor, 1997) and provide evidence for the types of activity that were occurring at the site and in the surrounding landscape during the later prehistoric period. Buckland and Sadler (1985) analysed insect faunas from alluvium adjacent to the Roman site at Sandtoft, providing evidence for the contemporary environment. Palaeoenvironmental work has also been carried out at Cowick, a medieval moat site (Hayfield and Greig, 1989) (See Figure 1.1 for site locations).

2.4 Palaeoenvironmental work and archaeological synthesis

The following account describes each regional pollen assemblage zone, together with any associated archaeological evidence for the area of the Moors and the Humberhead Levels. Much of the following evidence comes from Mather (1991) and Smith (1985, *in press*) and follows their pollen assemblage zone nomenclature ("HLF" from Mather and "HHL" from Smith). Figure 2.1 summarises the vegetational zones recorded from the Humberhead Levels. The account commences *c.* 5500 cal BC, when peat initiation began in the Torne floodplain (Mather, 1991).

Evidence for the regional vegetational changes during the early part of the Holocene comes from beyond the Humberhead Levels, at Tadcaster and Burton Salmon in the Vale of York (Bartley, 1962; Norris *et al.*, 1971) and the floodplain of the River Trent at Bole Ings, near Gainsborough (Dinnin, 1997e; Brayshay and Dinnin, *in press*).

2.4.1 HLF/1: Pinus-Betula-Salix zone; c. 6000-5500 cal BC (c. 8000 BP)

During this period, *Betula*, *Alnus* and *Salix* probably grew on the floodplain, with *Pinus* and *Corylus* dominating the surrounding Sherwood Sandstone. Mather (1991) recorded relatively high values of *Pinus* and to a lesser degree *Betula*, *Alnus* and *Salix* in the basal peats associated with a palaeochannel of the River Torne at Hayfield Lodge Farm, Rossington. These taxa, in association with occasional grains of *Quercus*, *Tilia* and *Ulmus* led him to correlate his zone to the latter part of Godwin's pollen zone VI. High frequencies of microscopic charcoal, together with fluctuations of *Pinus*, *Betula* and *Corylus* pollen led him (*ibid.*) to suggest Mesolithic exploitation of the contemporary forest using fire.

2.4.2 HLF/2a: Alnus-Ulmus-Tilia zone; c. *5320-4000 cal BC* (c. *6300-5200 BP)*

Alnus probably dominated the carr woodland which developed during this period, particularly in association with the floodplains. A mosaic of *Quercus*, *Ulmus*, *Tilia* and *Betula* forest, together areas of *Corylus* or *Alnus*, probably covered large areas (Mather, 1991). On sandy soils *Pinus* was probably the dominant tree.

Mather (1991) recorded a marked *Alnus* rise at the opening of this period, appearing to mark the onset of this tree's domination of the floodplain vegetation for much of the prehistoric period. The only radiocarbon date available for this event in the region comes from Bole Ings, Nottinghamshire, where a date of 5360-5070 cal BC (6290 ± 70 BP, Beta-75272), was obtained for the *Alnus* rise (Dinnin, 1997b; Brayshay and Dinnin, *in press*). However, as Dinnin (1997b, 36) has pointed out, the spread and expansion of *Alnus* was a diachronous phenomenon and although there was a major expansion of *Alnus* at many sites from about *c.* 7,500 - 6,500 years ago (Chambers and Elliott, 1989), the extrapolation of the radiocarbon date from Bole Ings over a large area should be viewed with caution. In association with the *Alnus* rise was the spread of *Tilia* (one of the most important tree taxa in lowland mid Holocene forests [Greig, 1982]), together with rises in *Quercus* and *Ulmus*, suggesting the establishment of dense fen-carr woodland in the river Torne floodplain (Mather, 1991).

Archaeologically, this and the previous vegetational zone span the late Mesolithic. Several Mesolithic sites have been located in the Humberhead Levels. The flint scatters recorded by Buckland and Dolby (1973) at Misterton Carr are now known to be part of a series of lithic scatters associated with sand levées adjacent to a palaeochannel of the River Idle. The majority of sites probably date to the late Mesolithic/Early Neolithic (Dinnin, 1997b; Head *et al.*, 1997b), although the scatters at both Misterton and Haxey date, at least in part, from the early Mesolithic (Buckland and Dolby, 1973).

Other finds of flint flakes, blades, scrapers or waste have been attributed to the Mesolithic period; the distribution of many of these finds seems to coincide to a high degree with the presence of rivers or their palaeochannels (Van de Noort and Fenwick, 1997, 223). This may be the product of the "visibility" of the archaeological record in these locations. A late Mesolithic scatter is recorded on the north bank of the Old Don, near Breir Hill beyond the southern edge of Thorne Moors (Hatfield Woodhouse 6 of Head *et al.* 1997b). A Mesolithic tranchet axe and flint flakes have been recorded from sand ridges protruding through the wasting peats of Nun Moors, between Thorne Moors and Thorne (Magilton 1977; Van de Noort *et al.* 1997). A late Mesolithic/Early

Neolithic flint scatter is situated on a ridge of windblown sand protruding through peat and alluvium on the eastern bank of the Old Don as it skirts the present-day eastern margin of Crowle Moors (Crowle 2 of Head *et al.* 1997b; Dinnin 1997b). Two large late Mesolithic/Early Neolithic flint scatters have been recorded from sand levées of a palaeochannel of the River Torne, *c.* 500 m from the southern boundary of Hatfield Moors (Wroot 3 and 4 of Head *et al.* 1997b; Dinnin 1997b).

2.4.3 HLF 2a/b boundary and 2b: Ulmus decline and Alnus-Quercus-Corylus zone; c. 4000 - 2900 cal BC (c. 5100- 4300 BP).

Mather (1991) recorded a marked decline in *Ulmus* pollen at the boundary between HLF 2a and HLF 2b, followed by records of agricultural indicator species. Subsequent fluctuations in *Pinus* and *Quercus* and light-demanding *Corylus* and *Fraxinus* were interpreted as evidence of small-scale clearance disturbances, followed by secondary forest regeneration. Mather dated the decline to approximately to 4000 cal BC (5,100 BP), after Edwards (1988). Shortly after the *Ulmus* decline, Mather recorded declines in many arboreal species, which he interpreted as being due to anthropogenic activities. This probably took place upon the adjacent higher ground, as the continued high levels of *Alnus* suggested a continuation of the fen-carr woodland on the River Torne floodplain. A.G. Smith (1958a) also identified an *Ulmus* decline at Hatfield Moors, but B. Smith's (1985) subsequent investigations showed that the sequence had a later origin. Smith (1985) interpreted the low values of *Ulmus* pollen at the opening of the pollen sequences from Thorne and Hatfield Moors as indicative that the sequences post-date the *Ulmus* decline and highlighted the levels of human interference upon forested environments during this period. The evidence from Hayfield Lodge Farm support Smith's (1985) interpretation.

Following the *Ulmus* decline, Mather (1991) found subsequent fluctuations in the representation of arboreal species, including *Pinus, Quercus, Corylus* and *Fraxinus.* He interpreted this as evidence for small-scale disturbances. During his zone HHL2b further evidence for Neolithic clearances was evident, followed by pastoral agriculture and forest regeneration.

From this period onwards, the peats of Thorne and Hatfield Moors have provided the main record of vegetational changes for the later prehistoric and historic period in the Humberhead Levels. The regional pollen zones devised by Smith (1985), amended by Smith (*in press*), are utilised to illustrate the successive regional vegetational changes.

2.4.4 HHL/A: Quercus-Corylus-Pinus zone; c. 2900 - 1930 cal BC (c. 4300-3600 BP)

Diverse *Quercus-Tilia-Corylus* dominated forest probably grew on the clayey Drift and Mercia Mudstone derived soils, with *Alnus* forming an important component in more poorly drained areas (Smith, 1985). Even before growth of peat, the area of the two Moors would have been low-lying, prone to waterlogging and with impoverished soil (Dinnin, 1997c). The importance of *Tilia* in this area is indicated by fossil insect assemblages from sites beyond the present boundaries of the two Moors, such as Thorne Waterside (Buckland, 1979) and Misterton Carr (Osborne, 1978). *Pinus* grew close to or on the drier parts of the mire, for example on Lindholme, on the sand dune system which forms the base of Hatfield Moors, as well as on large areas of Thorne Moors. Part of this zone over-laps with Mather's (1991) *Alnus-Quercus-Corylus* zone, described above.

This and the previous pollen zone span the Neolithic period. As with the Mesolithic, many of the finds and flint scatters recovered appear to be closely correlated with rivers or their palaeochannels (Van de Noort and Fenwick, 1997). Again, this may be the product of "visibility". Late Neolithic flint scatters have been found on the eastern bank of a palaeochannel of the River Went on the western side of Thorne Moors (Dinnin, 1997b; Hatfield Woodhouse-6 of Head *et al.*, 1997a). A significant flint scatter was recovered adjacent to the palaeochannel of the Went, north of Moorends, close to Thorne Moors (Gaunt, 1987; Moorends-5 of Van de Noort and Fenwick, 1997). Small concentrations of finds have also been recovered at Kirk Sandall, on the River Don, at Cantley, at Auckley Common and Wroot on the River Torne, at Scaftworth and Misson on the River Idle (Van de Noort and Fenwick, 1997). Several Neolithic stone axes have been found on blown sands abutting the Isle of Axholme near Westwoodside, at the edge of the wetland complex (Westwoodside-4 of Head *et al.*, 1997b). An assemblage of Neolithic material was also recovered from Misterton Carr (Buckland and Dolby, 1973). At Clouds Lane Farm, Belton, flint and stone tools have been recovered in a relatively small area (Loughlin and Miller, 1979). In the vicinity of Wroot, a polished jadeite axe, probably Neolithic, has been recovered (Campbell-Smith, 1963).

During the late Neolithic there is evidence of occupation on one of the larger of the two islands at Sutton Common, Enclosure A, in the form of flint-work (Buckland *et al.*, 1997c), described in detail by Head *et al.*, (1997a, Askern-6, 235). The flint seals further post holes, possibly Neolithic in date (Merrony, *pers. comm.*). Nearby, to the east of the peat in Shirley Wood, is a burial mound, probably Neolithic (Buckland *et al.*, 1997a; Askern-8 of Head *et al.*, 1997a).

The only securely provenanced contemporary archaeological evidence from either Moors is a possible Neolithic flint blade from the western part of Thorne Moors (Dinnin, 1994). Warping of much of the land surrounding the Moors has impeded archaeological investigations particularly to the north and west; nonetheless, there is artefactual evidence for contemporary and earlier human activity (Head *et al.* 1997a). A polished axe has been found at Greenland Farm, north of Thorne Moors (D. Hey, *pers. comm.*) and a variety of flint flakes are recorded from sand ridges protruding through the wasting peats of Nun Moors, between Thorne Moors and Thorne (Magilton 1977; Van de Noort *et al.*, 1997).

2.4.5 HHL/B: Quercus-Corylus-Alnus zone; c. 1930-480 cal BC (c. 3600-2300 BP)

The pollen record from both Moors suggested relatively small-scale forest clearance for pastoral agriculture of land around the raised mires from *c.* 2280-2030 cal BC (3715 ± 70 BP, CAR-233) and 2200-1970 cal BC (3685 ± 65 BP, CARR-256). This was indicated by declines in *Pinus* and *Tilia* pollen and increases in Poaceae, *Plantago lanceolata* and *Pteridium*. Smith (1985) suggested that during this period forest on the higher ground in the vicinity of Thorne Moors (e.g. Thorne, Moorends and Crowle) and Hatfield Moors (e.g. Lindholme, Hatfield) was being cleared for small-scale pastoral farming. These areas were then abandoned, perhaps after only 200 years, allowing woodland regeneration. There followed a period of more intensive forest clearance for pastoral farming. Both Moors show evidence for these early/middle Bronze Age clearance/pastoralism episodes, followed by early Iron Age regeneration and subsequent expansion of forest clearance (Smith, *ibid.*). Spatial variations in the timing and longevity of these phases both within and between the two Moors have yet to be elucidated (Smith, *ibid.*).

Smith (*ibid.*) obtained radiocarbon dates on charcoal horizons within the peats on Thorne and Hatfield Moors of 2280-2030 cal BC (3715 ± 70 BP, CAR-233) and 2040-1780 cal BC (3570 ± 70 BP, CAR-169), respectively. The charcoal horizons apparently coincided with the onset of human activity, although such a correlation could be questioned (see section 7.8.2.2). This, together with the pollen evidence for forest clearance and a record of a burned and chopped *Pinus* stump from Crowle Moors, radiocarbon-dated to 2030-1770 cal BC (3545±70 BP, CAR-313) led Smith (1985) to suggest the deliberate use of fire for forest clearance. Recently, extensive areas of charred *Pinus* trunks and stumps on both Moors were investigated (Whitehouse, 1993, 1997; Dinnin 1994; 1997c). The charred trees were found to be associated with fossil beetle faunas containing many rare or nationally extinct taxa (Whitehouse, 1993, 1997a). Although Smith (1985) argued for an anthropogenic cause for the charcoal horizons, other researchers have suggested that they could represent natural fire events, particularly since *Pinus* forest growing on a dry mire would be prone to combustion (Whitehouse, 1993, 1997a; Dinnin, 1997c).

Palaeoentomological research associated with the Bronze Age trackway was carried out together with a very limited pollen investigation (Buckland and Kenward, 1973; Buckland, 1979). Fossil insect assemblages from the base of the peat were dated to 1450-1220 cal BC (3080 ± 90 BP, BIRM-336), which agreed closely with the date for the primary *Tilia* decline (1320-1010 cal BC, [2942 ± 115 BP, Q-482] and 1320-1000 cal BC [3170 ± 115 BP, Q-481]) (Turner, 1962; Smith, 1985). The beetles from the woody basal peat were characteristic of an *Urwald* fauna, a term often used to describe species which are found in undisturbed, ancient woodland and included seven species no longer found in Britain (Buckland 1979). Buckland and Kenward (1973) suggested a limited phase of Bronze Age clearance on Thorne Moors based on the association of the trackway, charred tree remains and cereal pollen grains. Smith (1985) subsequently concluded that the "cereals" were likely to be *Glyceria* pollen (i.e. wetland grass).

At Hayfield Lodge Farm, Mather (1991) identified pollen evidence for two phases of forest clearance, probably related to clearance for pastoral agriculture during the late Bronze Age and Early Iron Age. The episodes culminated with a decline in arboreal taxa, particularly of *Tilia*. Mather interpreted this evidence as implying widespread forest clearance on the surrounding Sherwood Sandstone at this time. Evidence from the Iron Age enclosures at Sutton Common also supports this impression (Parker-Pearson, 1997a). Buckland and Magilton (1986, 11) suggested that the Levels were probably cleared of natural woodland at least as early as the beginning of the Iron Age.

Beyond the trackway at Thorne Moors, the only other known site of this period is at Sutton Common, where a concentration of Bronze age metalwork (Buckland *et al.*, 1997b) has been recovered. A bronze dagger blade fragment has been dated typologically to around the twelfth-eleventh centuries uncal BC (Parker-Pearson, 1997a, 32). Other finds also indicate continued human presence within the region, such as the discovery of a Bronze Age hoard from the present edge of Crowle Moors (Davey, 1973). An adze-palstave has been recorded from Moorends, on the western perimeter of Thorne Moors (*ibid.*). Other Bronze age finds include a palstave from Misson, a looped-socketed spearhead from Hatfield and a rapier from Austerfield (*ibid.*). Axe hoards have also been recovered from Keadby and Haxey (Davey, 1973); there are stray bronzes from Haxey, Goole, Sandtoft (Davey, 1973) and West Butterwick (Loughlin and Miller, 1979) and a gold ribbon torc with "ring-money" from Low Burnham, Haxey, (Davey, 1973, 91). There is also a small collection of Bronze Age pottery in Doncaster Museum from the area (Manby, 1973). More recently, a large assemblage of pottery in the Beaker tradition has been recovered from Auckley, close to the River Torne, which represents one of the largest collections of prehistoric pottery in south Yorkshire (Chadwick, 1995).

There is only one known early Iron Age site in the Levels, which is the double-enclosure (or marsh fort) at Sutton Common, one of few wetland sites of its age in Britain. Parker Pearson (1997b) suggests that it was a settlement site, but that it may have had an important ceremonial or high status significance. Environmental evidence from the enclosures indicates the sites were located in an *Alnus* dominated carr, with some evidence for meadows and grassland replacing the carr landscape during or after the early Iron Age (Parker Pearson, 1997a; Roper and Whitehouse, 1997).

2.4.6 HHL/C: Poaceae-Plantago-Pteridium Zone; c. 480 cal BC - cal AD 440 (c. 2335 - 1445 BP)

The beginning of this zone coincided with Turner's (1962) "secondary *Tilia* decline" (dated to *c.* 760-260 cal BC [2335 ± 40 BP, CAR-189]) and appears to span the middle Iron Age to about the end of the Roman period. *Tilia* had decreased to such an extent that thereafter this species was almost totally absent from pollen diagrams of the area. Such a permanent decline in this taxon is a feature of many pollen diagrams of this period from lowland sites in Britain (Smith, 1985), and is likely to be associated with human activities (*cf.* Turner, 1962, 1965). However, recent research suggests that the reduction in *Tilia* pollen representation may be also be a product of the process of paludification rather than representing a reduction of *Tilia* woodland (*cf.* Waller, 1994).

This zone represented a period of regional deforestation for agriculture. The pollen of clearance herbs was well represented and Smith (1985) concludes that a mixed farming economy, with an emphasis upon pastoralism, was being practised. High values for *Calluna* were also obtained, underlining the significance of this species. The palynological data suggest that the landscape was open, an impression which is supported by the palaeoentomological research carried out by Buckland and Sadler (1985) at Sandtoft, east of Hatfield Moors. Further east, at Dragonby in north Lincolnshire, the fossil insects from an early Roman well, indicated a wholly cleared, pastoral landscape, with few faunal elements associated with trees (Buckland, 1996).

Mather (1991) recorded evidence for widespread forest clearance at Rossington, with a dramatic decline in all arboreal taxa and a rise in Poaceae. There were tentative identifications of some crop plants, such as *Hordeum*, *Avena-Triticum* group and possibly *Cannabis*. The decline in *Alnus* and an increase in Cyperaceae was seen as indicative of increasingly waterlogged conditions on the floodplain during the Roman period. In the Idle floodplain, away from the *Alnus*-dominated carr woodland, the landscape here also was essentially open and farmed (Gilbertson and Blackham, 1985).

The impression of an open landscape is supported by the archaeological, particularly aerial photographic evidence (*cf.* Riley, 1973; 1976; 1980, 1983; Chapman, 1997). This evidence suggests that a large number of field systems and enclosures date to this period, such as those at Sandtoft, the Isle of Axholme, Epworth, Rossington, Dunsville (Edenthorpe) and Hatfield. Within the Humberhead Levels, eighteen enclosure and settlement sites have been identified by aerial photography (Chapman, 1997). Many of the sites appear to be distributed in those areas where Sherwood Sandstone and older river gravels outcrop (Van de Noort and Fenwick, 1997), although these well-drained substrates exhibit more visible crop marks (Riley, 1980). Deggan (1996) points out that the field systems may have been present on the heavier clay soils to the east, where considerable tracks of medieval and post-medieval ridge and furrow are still upstanding, which might obscure any earlier field boundaries. Many of these field systems appear to be at least pre-Roman in date (Magilton, 1978; Riley, 1980; Chapman, 1997). As Buckland (1979) discusses, much of the evidence seems to underline the continuity of landscape tenure from the Iron Age into the Roman period; it is difficult to believe that some of the "Roman" field systems did not have Iron Age or even earlier antecedents. The palynological evidence supports the impression of cleared areas from the Bronze Age onwards (cf. Smith, 1985; Mather, 1991; Brayshay and Dinnin, *in press*), so it is not inconceivable that some field boundaries may have had their origins in the Bronze Age.

There also appear to have been considerable settlements of this date around the margins of Hatfield Chase, at Gringley, Everton, Bawtry, Misson and Finningley, as well as an urban centre at Doncaster (Buckland and Magilton, 1986). Romano-British sites have also been identified north of Thorne, near Tudworth, as well as close to Misterton Carr (Head *et al.*, 1997b). Some of these settlements may have had Iron Age predecessors (Buckland and Dolby, 1973). A series of Romano-British sites have also been identified on raised areas abutting the eastern and southern margins of Thorne Moors and the southern and north-eastern margins of Hatfield Moors (Moorends 3-6 of Head *et al.*

1997b; Lillie 1997a). In addition to settlement sites, there were several Roman forts in the Levels (Riley, 1980; Buckland, 1986, 1997) and pottery industries (Buckland, *et al.*, 1980; Chapter 10), which probably utilised the river system to transport raw materials and goods. With evidence for possible early Roman diversions of the Rivers Don and Idle, extensive cropmarks, sites and surface finds, the evidence suggests that the landscape of the Levels was part of an organised socio-political, economic and agricultural system.

The soil erosion noted by Buckland and Sadler (1985) may be related to over-use of soils during the Roman period. Evidence for abrupt alluviation at Sandtoft, on the eastern side of Hatfield Moors, has been dated to the latter part of the Roman period (Buckland and Sadler, 1985). The changing character of alluviation has been observed at other Roman sites across the Levels and the Lower Trent (Riley *et al.*, 1995). Buckland and Sadler (*ibid.*) suggest that a widespread change in agricultural techniques in the area may have led to destabilisation, causing a massive input of sediment into the rivers, whilst Jones (1995) suggests that the neglect or abandonment of artificial canals, such as Turnbridge Dike and Bycarrsdike (possibly Roman), could have been a contributory factor.

2.4.7 HHL/D: Quercus-Corylus-Betula zone; c. 440-1000 cal AD (c. 1445-860 BP).

This period is characterised by a decline in herb taxa and a regeneration of tree and shrub pollen, possibly indicating the re-colonisation of abandoned land by scrub woodland. Smith (1985) interpreted this phase as evidence for post-Roman agricultural decline and woodland regeneration, followed by agricultural expansion at the beginning of the Anglo-Saxon period. He also noted that land abandonment coincided with a possible marine transgression, the result of a small rise in sea levels at this time. Other researchers have suggested a discontinuity in territorial organisation between the Roman and Anglo-Saxon periods in this area (Unwin, 1983). Alternatively, settlement nucleation during the post-Roman period could explain this pattern. The end of this period showed a slight resurgence in agricultural activity (Smith, 1985).

There are many documentary accounts for this period (see Cory, 1985; Metcalfe, 1960), although archaeologically there is very little contemporary artefactual evidence.

2.4.8 HHL/E: Poaceae-Cannabis-Secale zone; c. cal AD 1000 onwards (c. 900 B.P.)

This phase is marked by a decline in tree and shrub pollen. Pollen grains of clearance herbs are well presented, together with those of *Cannabis*, *Secale*, *Hordeum* and weed species associated with arable agriculture. This probably reflects increased woodland clearance and intensification of agricultural activities. Peat cutting and disturbance truncates this zone, which in places is entirely absent (Smith, 1985).

Archaeologically, this zone is represented by the Norman, medieval and post-medieval periods. After the Norman Conquest, Thorne and Hatfield Moors, as part of the estate centred on Conisborough, were awarded to William de Warenne (Birch and Ryder, 1988). Sometime in the Middle Ages the Moors and their surroundings became part of the great hunting estate of Hatfield Chase. The Domesday survey shows that by 1086 only 16% of the West Riding was wooded and the lowland Doncaster region had a mere 9% woodland coverage (Howes, 1997). The Chase was thus not heavily wooded, but probably became part of a hunting estate because of its high red deer population and was subject to Forest Law in 1460 (Cory, 1985). Wagner and Pelling (1995) argue that some indication of what these medieval hunting forests may have looked like can be glimpsed on the remnants of Skipwith Common today, in the Vale of York, which supports areas of open heathland and wet mire (Plate 2.1).

At Cowick, near Snaith and northeast of Thorne Moors, a royal hunting lodge was located. Environmental work on the contents of its moat was undertaken in the course of dredging work (Greig, 1986; Hayfield and Greig, 1989). The investigations suggest that the lodge was set within a landscape with elements of meadowland and ancient woodland.

Historical accounts indicate that Hatfield Chase was also used for fisheries, turbary, as well as pasturage (see Metcalfe, 1960). The Domesday book lists twenty fisheries in Hatfield Chase (Hey, 1986). During winter months, before drainage, part of the area was under water and temporary lakes (meres) formed (Dunston, 1909). Thorne town had a mere which has since disappeared (see Taylor, 1987). Documentary evidence suggests that the mere was in close proximity to Thorne Waste, possibly in the area of the "Canals" region (south side of Thorne Moors), where a major change in the stratigraphy has been noted (Rogers and Bellamy, 1972; Smith, 1985). Drained in the seventeenth century, the Mere was a freshwater lake on the Old River Don and was an important source of wealth, with fish stocks carefully controlled and managed (Tomlinson, 1882)

There was an active medieval pottery industry in the Humberhead Levels. During the thirteenth century an important industry was centred around Doncaster, but after this period production appears to have moved away from the market centres to rural settlements, such as those at Cowick (Buckland *et al.*, 1979). These centres probably utilised the many watercourses in the area to transport products and made use of local coppice and turbary resources from the Moors (Buckland *et al.*, 1979).

2.5 Bog Bodies

The discovery of bodies is well-known from other localities, particularly on the Continent, but also from the bogs of Ireland and Cheshire Mosses (e.g. Lindow Moss; Turner, 1995). Human remains have been recorded from in and around Hatfield Chase, particularly during peat cutting for the seventeenth century drainage and canalisation works. Accounts such as those of Richard Richardson of North Bierley, Nathaniel Johnson of Pontefract and Abraham de la Pryme list buried trees, plough marks and coins, as well as bodies found in the vicinity of these Moors (Turner and Briggs 1986, 145). Stovin (1730) also recorded the discovery of a number of bog bodies in this area, including his account regarding the Amcotts woman, which Turner and Rhodes (1992) suggest is late Roman in date. Turner and Briggs (1986, 146) argue that this area is the most important in England for bog burials and suggest that many bodies probably date to between the Iron Age and the end of the Romano-British period, with some being of Saxon or even later date. Further details of the bog bodies recovered are summarised by Briggs and Turner (1986), Turner and Scaife (1995) and Van de Noort and Fenwick (1997).

CHAPTER III: PALAEOENTOMOLOGICAL APPROACHES AND METHODOLOGY

3.1 Quaternary palaeoentomology: a review

This review summarises the history of palaeoentomology and examines some of the themes and issues that have been highlighted by this discipline. Elias (1994) has recently provided a detailed review of Quaternary palaeoentomology. Much of the following account largely concentrates upon the north European literature and considers literature pertinent to this research.

Insects are very sensitive to environmental change and occupy almost every possible ecological niche and type of habitat on land and freshwater. Their diversity enables them to be utilised as proxy data for a wide variety of habitats and climatic conditions (Elias, 1994, 55). Palaeoentomology is a multi-disciplinary subject and has contributed to a range of disciplines, including ecology and palaeoecology, geology, biogeography, climatology, archaeology as well as providing much valuable information to modern insect studies (Morgan and Morgan, 1987). Research has provided important palaeoclimatic data recording the transition from arctic to temperate conditions during the Late-Glacial (e.g. Lowe and Walker, 1997), as well as highlighting the scale of environmental changes, particularly during the last 5,000 years of the Holocene (Buckland and Coope, 1991). Studies have also provided some important biogeographic data on species longevity, centres of origin and stability of insect communities (Coope, 1978, 1995; Elias, 1994). For instance, species origins are often seen to be centred upon modern distributional ranges, but the fossil record indicates this is far too simplistic (e.g. Coope 1973, 1995).

Although most insect fossils identified generally belong to the Coleoptera, other insect groups are available for analysis, such as the Chironomidae (Diptera) (Walker *et al.*, 1991; Brooks *et al.*, 1997a, b; Sadler and Jones, 1997) as well as other Dipterous remains (Skidmore, 1995) and Trichoptera (Wilkinson, 1984). Hymenoptera are often well represented and groups such as the Formicidae (ants), which are plentiful in deposits from the Levels, would merit specialist attention. Other arthropod groups such as mites (Acarina) have received some study, elsewhere in Europe, notably by Karppinen and Koponen (1973; 1974) and Schelvis (1987; 1997).

Carl Lindroth (1948) and Scandinavian entomologists established foundations for the modern discipline in the 1930s and 1940s. In the mid 1950s, the centre of research activity moved to Britain and particularly to the geology department at Birmingham

University (Morgan and Morgan, 1987). In 1955, Russell Coope began studying Quaternary insect fossils from Upton Warren, near Birmingham (Coope *et al.*, 1961). By making comparisons with modern specimens, Coope matched most of the material with modern species and showed that insects had remained evolutionally stable in their morphology and their environmental requirements throughout the whole of the Quaternary period (Coope, 1970). Recent research has highlighted the constancy of exoskeletal as well as genital characteristics over long periods of time (Angus, 1997). Evidence for evolutionary change is extremely rare from Quaternary insect assemblages. John Matthews, working in Alaska, was been able to show morphological changes in Upper Tertiary insect faunas (Matthews, J.V., 1970, 1974), but even here, the changes were only slight. More recent research from the far north of Greenland has confirmed Matthews' assertions (Böcher, 1986, 1997).

It appears that the overall composition of the assemblages of insects species which occur today, at least in the temperate zones, were established during late Tertiary times (Matthews, 1970), with very similar fossil insect assemblages recovered during different glacial, interglacial and interstadial climatic episodes (Elias, 1994). Coope (1978, 1995) has shown that insects respond to climate change by undergoing distributional shifts. These shifts have been sufficiently frequent to prevent the genetic isolation of populations that would have led to speciation. Coope (1995) further suggested that rapid speciation (for example amongst some of the mammals) requires environmental stability in a constant geographic location. Large-scale tracking of suitable environments meant that insect populations were constantly splitting up and reforming as they progressed backwards and forwards across the landscape in response to climate change. The effect of such movement would have been to keep the gene pool constantly mixed. Coope (1995, 68) concluded that *"sustained evolution under such circumstances must have been almost impossible"*. Such evidence has interesting implications with regard to evolutionary theory and the response of organisms to environmental change (*cf.* Bennett, 1997).

A succession of studies in the early 1970s by Coope and co-workers showed that beetles were responding to a series of very rapid climate changes of greater amplitude than those deduced from the pollen record (Coope and Brophy, 1972; Coope and Joachim, 1980; Osborne, 1972, 1980; Ashworth, 1972, 1973). This record is impeded by the slower migration rates of plants, particularly of trees. Through work on many sites Coope has been able to produce a composite palaeoclimatic curve for much of the Devensian across northern Europe (Coope and Brophy, 1972; Coope, 1977; Walker *et* *al.*, 1993). His palaeoclimatic interpretations are now generally accepted for Western Europe (Lowe and Walker, 1997). The rapid changes from cold to warm conditions during the late Devensian, possibly as rapidly as fifty years during the Devensian/Flandrian transition (Ashworth, 1972, 1973; Osborne, 1974; 1980), had not been reflected in the pollen record. Recent work on the Greenland ice cores suggests climatic warming of 7 °C within 50 years after the termination of the Younger Dryas (Dansgaard *et al.*, 1989). There is a particularly good correlation between the palaeoclimatic curve derived from fossil insect sites in the British Isles and those derived from the Greenland Ice core and other proxies (Coope and Lemdahl, 1995; Lowe and Walker, 1997), although local as well as regional influences can have important effects upon results (Coope and Lemdahl, 1995; Vandenberghe *et al.*, 1998; Coope *et al.*, 1998).

The quantification and standardisation of palaeoclimatic data have been aided by the development of the Mutual Climatic Range (MCR) method (Atkinson *et al.*, 1987; Coope *et al.*, 1998). The basic assumption of MCR is that if the present climatic tolerance range of a beetle species is known, then fossil occurrences of that species imply a palaeoclimate that lies within the same tolerance range. Insects react very quickly to climate change, as they are very mobile and have annual generations; some species live in very narrow temperature ranges, and by overlapping the modern distributions of the fossil species, it is possible to pinpoint mean winter and summer temperatures to within a few degrees (Elias, 1994). The palaeoclimate is reconstructed by using the mutual intersection of modern climatic ranges of selected species in the fossil record (Atkinson *et al.*, 1987). Coleoptera are especially suitable for this technique, as they are a varied group where many species show fairly well defined tolerance ranges. Carnivorous and scavenging beetle species are usually utilised as they are able to respond more rapidly to climate change and they are not tied to specific types of vegetation (Coope *et al.*, 1998).

The application of the MCR technique has seen the production of palaeoclimatic curves for almost the last 45,000 years (Walker *et al.*, 1993; Lowe and Walker, 1997), at least for northern Europe. MCR palaeotemperature estimates for the last glacial-Holocene transition are now available from 77 sites in northern Europe (Coope *et al.*, 1998). Elias (1996, 1997; Elias *et al.*, 1996) has also applied MCR to insect assemblages from the American continent. However, MCR has received some criticisms. Andersen (1993) called into question the ability of beetle remains to provide accurate indicators of macroclimate, suggesting that the selection of warmer microhabitats within a cooler macro-climate could affect the thermal values obtained from MCR (Andersen, 1993). Coope and Lemdahl (1996) responded to his criticisms by suggesting that Andersen had misunderstood the MCR method and that the effects that he referred to were already taken into account in the MCR technique. Andersen (1996), however, remains unconvinced.

MCR has not been widely applied to European Holocene faunas. Hellqvist and Lemdahl (1996) attempted MCR on Carabidae from medieval deposits in Uppsala, Sweden. The authors concluded that the climate was similar to the present, although summer temperatures may have been slightly warmer. However, the number of species they utilised in the MCR reconstruction was rather limited and the evidence seems rather inconclusive. In this study, MCR has not been utilised. The ground or scavenger beetles recovered are un-suitable for palaeoclimatic work, since they all continue to live in Britain and do not appear to indicate any thermal preferences. In addition, the faunas are very limited amongst these groups. Species which may have been interpreted as potentially indicating climate change (species which have become extirpated in mainland Britain) could not be utilised as they are habitat/host specific and their distribution is more likely to be tied to habitat availability and longevity rather than thermal preferences.

Despite the success in examining Late-Glacial climate change, the palaeoentomological record for the Holocene remains elusive (Wagner, 1997). Palaeoecological studies dating from the mid-Holocene onwards highlight the increasing scale and extent of human impact (Osborne, 1965, 1978, 1997; Buckland, 1979; Girling, 1982b, 1985). For instance, British forests had reached their maximum development by the mid-Holocene and both pollen and fossil insect evidence suggest that by the Bronze age (*c.* 2500-800 cal BC [4000-2700 BP]) a significant reduction in their areal coverage had occurred (e.g Robinson, 1991). Transitions from forested to cleared landscape (termed "culture steppe" by Hammond [1974]) have been observed across a number of locations across Britain (e.g. Girling, 1985, 1989; Dinnin, 1992). In consequence, by the Iron age (*c.* 800 cal BC - 43 cal AD, 2700-1900 uncal BP) mature woodland beetle species appear to represent an insignificant faunal element (Osborne, 1972; Girling, 1979b, 1982b, 1985; Robinson, 1979; 1993). Faunal changes similar to those experienced in Britain during the late Bronze Age were recently observed in deposits in north-east Iowa (Schwert, 1996). Baker *et al.* (1996) found profound changes in the native insect fauna as a consequence of Euro-American settlement, illustrating the extent to which human activities can destabilise landscapes.

Data clearly indicate that not only is human impact of considerable importance, but that it may swamp and mask low magnitude climatic events. Osborne (1969, 1976, 1982) attempted to examine the distribution of beetles linked to habitats which are less subject to human disturbance. He concluded that there was some evidence to suggest that between four and three thousand years ago summer temperatures were higher than the present day, declining to present levels during the Iron Age and remaining more or less constant until the "Little Ice Age" (Osborne, 1982; Girling, 1984). Insect faunas have not produced any evidence for the period known as the "Medieval Warm Period" (*cf.* Hughes and Diaz, 1994). However, the effects of climatic deterioration during the "Little Ice Age" (Grove, 1988) have still to be fully evaluated, (see Buckland, 1975; Buckland *et al.*, 1983; Girling, 1984; Dinnin, 1997e; Osborne, 1997a). A recent paper by Wagner (1997) suggests that this episode had minimal impact upon British insect faunas, although few deposits spanning this period have been investigated.

Much of the Holocene record has been researched through the increasing use of palaeoentomology in archaeological investigations. Many of the investigations have concerned non-urban sites, ranging from the analysis of material from the Somerset Levels associated with Neolithic and Bronze Age trackways (e.g. Girling 1976, 1977, 1978, 1979a, 1979b, 1980), trackways in the Gwent Levels (Smith *et al.*, 1997) to Iron Age enclosure sites (Chowne *et al.*, 1986; Robinson, 1991, 1993). However, urban archaeological sites have often yielded copious insect material. The value of these deposits has been highlighted by work carried out at York (*cf.* Kenward and Hall, 1995) and elsewhere (e.g. Hall and Kenward, 1980; Greig, 1981). Kenward's work in York, in particular, has attempted to address some of the important taphonomic issues requiring consideration when examining fossil insects (1975, 1976, 1978, 1982; 1997; Kenward and Allison, 1994). Although much of his work concerns archaeological deposits, many of his considerations are important when reconstructing any fossil insect assemblage.

Kenward (1978) pointed out that the reconstruction of past environments operates upon one major assumption: that the ecological requirements of insects have not dramatically changed. The fact that groups of species have been consistently found together suggests that the ecological requirements of most species had not altered (Kenward, 1976). This does not signify that there have not been changes in insect distributions or that species have not become extirpated from the British Isles (see Chapters 6 and following). The difficulties of establishing the ecological requirements of single species and thus their significance in fossil faunal assemblages are considerable (Kenward, 1976). The available field data may not cover all available habitats and may include casual records.

Even when the biology of species is known in some detail, this may not cover all the suitable habitats, especially when microhabitats may provide suitable locations where the *overall* situation may provide a rather different ecological environment (*idem.*). Kenward (1975) also pointed out the difficulty associated with looking at a single species in fossil assemblages. Although he was referring to archaeological assemblages, this is applicable to looking at *all* assemblages. He urged the use of a large number of species and individuals when making reconstructions and that associations of particular species need to be recognised - the "mosaic" approach.

In contrast, other researchers (*cf.* Ervynck, 1994) have advocated the use of only certain groups of beetles for palaeoenvironmental reconstruction, for instance the Carabidae, which generally cannot fly and are unlikely to become incorporated within a deposit accidentally. However, such an approach excludes many species that provide very useful palaeoenvironmental data, including details about vegetational composition. Much useful information will be lost if only certain taxonomic groups are utilised in reconstruction and appears to reflect the approach of a growing number of modern entomological studies which consider only certain taxonomic groups (e.g. Butterfield and Coulson, 1983), rather than the diverse array of species which make up an ecosystem (e.g. Elton, 1966; Skidmore, *in press*). The mosaic approach, on the other hand, allows the identification of a certain habitat through the use of *many* species and ensures that adventitious taxa can be identified. *Groups* of species are utilised, which *together* are characteristic of a particular habitat. The mosaic approach has been taken in this research. The setting up of the BUGS data base at the University of Sheffield has greatly facilitated and contributed to the use of this approach (*cf.* Sadler *et al.*, 1992; Buckland, P.I. *et al.*, 1997).

A further step in palaeoenvironmental interpretation can be achieved through *species associations*, where a particular suite of species might be found consistently under certain circumstances. This type of approach has been recently refined by Kenward and colleagues (Kenward, 1997; Kenward and Hall, 1997; Hall and Kenward, 1998), who have attempted to identify types of deposit from a "signature fauna". However, such an approach has only been employed in archaeological assemblages.

3.2 Fossil insect studies of Holocene "natural" sequences

As discussed, much of the Holocene palaeoentomological material examined has been associated with archaeological investigations, either within an urban context or in rural locations. However, there has been a growth of palaeoentomological studies which have examined "natural" sequences (although the word "natural" is used, the author is well aware that very little of the British landscape has escaped anthropogenic impact of some sort or another). "Natural" sequences are deposits that are not associated with archaeological features, usually peat or alluvial sequences. Fluvial sediments often accumulate material, particularly in secondary channels bends, backflows and pools, as well as adjacent floodplain deposits (Macklin and Needham, 1992; Brown, A.G., 1997), such as those from Bole Ings, in the Trent valley (Dinnin, 1997e). Bogs and fens are also rich sources of "natural" fossil insect assemblages, although fen peats tend to be richer in insect remains than acid peats (Buckland, 1979; Roper, 1996). Anaerobic conditions ensure excellent preservation and the rapid built-up of deposits provides good temporal resolution.

Most of the deposits examined in this research fall within this category, particularly those from Thorne and Hatfield Moors. Of the two floodplain sequences examined, Misterton Carr is associated with a Mesolithic archaeological site (Buckland and Dolby, 1973; Osborne, 1978) and Hayfield Lodge Farm, Rossington, is located within a rich archaeological landscape. Both sites were selected to provide an overview of environmental change within their respective floodplains. However, very few floodplain deposits have been examined from a palaeoentomological point of view (*cf.* Kelly and Osborne, 1965; Buckland and Sadler, 1985; Osborne, 1988, 1995; Dinnin, 1997e), but they highlight the potential of such deposits.

In contrast, the deposits examined from Thorne and Hatfield Moors are completely un-associated with any known archaeology. There have been few projects that have studied fossil insects from mire deposits. All studies have concentrated upon Coleoptera, so present only a partial record of the insect fauna of wetlands. Some studies have concentrated on basal mire deposits or "forest" deposits at the base of mires (*cf.* Koponen and Nuorteva, 1973; Buckland, 1979; Girling 1985; Whitehouse, 1993) but none of these examined the whole succession through the mire. In fact, very few palaeoentomological studies world-wide have attempted to evaluate the effect of peatland development on the composition of an insect fauna (Lavoie *et al.*, 1997). One of the earliest investigations of material from a raised mire was carried out by Matthews (1980) at Klondike Bog, in Canada. A very small proportion of insect material was examined, which mainly consisted of species typical of fens and bogs. However, little or no utilisation was made of the insect evidence to examine the genesis and development of the mire. Girling (1982a) examined a fen peat succession associated with a trackway on Meare Heath, in the Somerset Levels, from the base of the peat to the top. She found evidence for recurrence surfaces, where fen plants colonised a former raised bog surface following the in-washing of calcareous water. Fen inhabitants reflected the raised bog/fen transition in the almost total replacement of raised bog insects. In Alaska, a shift from deciduous woodland to coniferous woodland and peatland insects was detected in a peat-bog from a 8,500 year sequence (Klinger *et al.*, 1990). Jordan (1995) carried out a limited study of a mire in Ireland. Roper (1996) showed how the transition from a minerotrophic fen to a more acidic raised bog at Thorne Moors caused a dramatic drop in insect diversity. The most extensive study to date has been carried out by Lavoie *et al.*, (1997), who recorded a 7,000 year sequence of insect communities from a peatland in southern Québec, Canada, together with associated plant macrofossil analyses. The research carried out on the material from the Humberhead Levels is presented within the context of such limited studies.

3.3 Sampling and identification procedures

Sampling of material suitable for fossil insect analysis entails the removal of material from an exposed section or bulk sampling from a particular context (e.g. archaeological context or fossil tree rot hole, for example). Samples are usually removed in 5-10 cm thick contiguous "slices". Occasionally it is possible to remove blocks of deposit (e.g. 50 cm x 50 cm), when non-friable deposit is being sampled. This approach allows the investigator to sample in the laboratory particular points in the stratigraphy and is preferable to the former approach. This investigation removed contiguous bulk samples, as peat was too friable to remove in intact blocks.

The extraction of fossil Coleoptera follows the technique devised by Coope and Osborne (1968). Each sample is disaggregated over a 300 μm sieve. Paraffin (kerosene) is mixed to the remaining material and cold water is added. The resulting flotant is then poured off, washed in detergent, rinsed and stored in ethanol. Sorting for insect remains is carried out under a binocular microscope. The identification of insect fossil material is carried out through the use of British and other European entomological keys and through direct comparison with a range of modern comparative material (Buckland and Coope, 1991). After identification, individuals are listed and counted.

CHAPTER IV: FIELD SURVEY PROGRAMME AND SAMPLING.

4.1 Survey work on Hatfield Moors

Whilst Thorne Moors has been extensively surveyed (Whitehouse, 1993; Dinnin, 1994, 1997c), no systematic survey work of Hatfield Moors had been carried out prior to this study. A field survey was initiated in the spring and summer of 1995 and additional fieldwork has subsequently been carried out by the Humber Wetlands Team (Dinnin, 1997c).

The survey was initiated to examine the following issues:

- Identify suitable palaeoentomological sampling sites to address the research questions.
- Record evidence for the nature of the pre-peat landscape.
- Record the nature and distributions of the palaeoforest preserved within the basal peats at Hatfield Moors and note any associated charring.
- Examine any possible evidence for the exploitation of fire as a forest management tool.
- Record any exposed archaeology.
- Record any stratigraphic information within the basal peats[1] that might aid the understanding of mire genesis and development and note any spatial or temporal difference observable across the mire.

A particular problem associated with fieldwalking working peatlands relates to the milling process. This process can leave much loose, surface peat, which can obscure archaeological/palaeoecological features of interest. Many of the ditches were relatively well maintained, however, so visibility was moderately good, and was not impeded by high water levels. Since this area continues to be milled for peat, all available information has been included in the field descriptions (Appendix B). All available ditches and sections were examined. In total, *c.* 300 km of ditches were examined.

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[1] The description of peat is made in conjunction with a comment on its humification level. It should be noted that these are subjective descriptions and peat profiles or samples have not been analysed for their humus content (*cf.* Aaby and Tauber, 1975).

4.2 Main field survey results

The following were recorded and mapped (Figure 4.1): the distribution and variation of fossil tree species composition; the distribution of charred material; the nature of the basal peats, together with the distribution of the sand dunes and any buried soil profiles; any archaeology. The survey enabled a series of palaeoecological sites to be identified and sampled. All results are discussed more fully together with the palaeoentomological evidence in Section 7.8. Figure 4.1 shows the location of all named areas.

4.2.1 The pre-peat landscape (non-woodland)

The survey work showed that the morainic ridge of Lindholme extends in a subdued form northward onto Kilham and southwards onto Ash Dump, forming a broad, low ridge beneath the peatland. This is increasingly exposed on Kilham West, Packards North sections 1 and 2 and West Ash Dump sections 1 and 2. The position of the "low causeway" described by De la Pryme (in Limbert, 1985) coincides with this ridge, suggesting that the "causeway" was this topographic feature. Dinnin (1997c) came to a similar conclusion.

Sand dunes occur closely related to the ridge, to the north and west, on Kilham East and West and south and south-west of Lindholme, on Packards North Sections 1 and 2 (Figure 4.1). In several places sand dunes overlay shallow morainic deposits (Plate 4.1a). Podzolic soils are buried beneath the peat and exposed along the sides of drainage ditches, particularly around Kilham West (Plate 4.1b). The stratigraphy, below the organic layer of the basal peat deposits, shows a leaching of the A horizon. This is followed by a horizon of dark reddish brown sand (the iron pan), below which are the yellow aeolian sands. No archaeological evidence associated with any of the sand dunes was recorded during the survey or during later fieldwork (Dinnin, 1997c).

4.2.2 The "palaeowoodland"

The survey allowed the recording of the distribution of the fossil forest, which is mapped in Figure 4.1. One of the major problems at Hatfield Moors, as had been found previously on Thorne Moors (Whitehouse, 1993; Dinnin, 1994), relates to the irregular topographic substrate and the uneven way in which peat extraction has taken place. This complicates the chronological understanding of the tree macrofossils. Whilst the distribution of exposed tree macrofossils *appeared* to relate to the same period, it is likely that different phases of the fossil forest and mire were exposed across the site.

The field survey revealed a small number of *Quercus* tree remains (*contra* Dinnin, 1997c), preserved in primarily marginal locations (Kilham West, Packards North section 2 and Tyrham Hall Quarry), on the western and southern side of Hatfield Moors. The low number of macrofossils suggests that *Quercus* was limited in distribution, although this could reflect selective preservation. *Pinus sylvestris* macrofossils were evident in distinct areas, as mapped in Figure 4.1.

Survey work in Tyrham Hall Quarry was particularly revealing. The density of the trees in this area was striking and mainly comprised *Pinus sylvestris*, some *Betula* and some scattered *Quercus* trunks (Plates 4.2 a, b). An area measuring c. 100 m by 100 m, which contained about 52 stumps and trunks, provided some measure of the density of the tree remains. There were a substantial number of tall, straight-growing trees. Some of the trees had very wide root systems. In one example, the width of the roots, from one end to the other, was *c.* 255 cm, with the main part of the trunk *c.* 55 cm in diameter. *Pinus* had rooted into the underlying aeolian sands, which still adhered to root formations. The state of many of the preserved trees was usually excellent, many retaining bark, with little indication of rotting.

Some of the *Pinus* showed animal and fire damage. One *Pinus* trunk was riddled with insect flight- and woodpecker-holes (see Plate 4.3a), indicating that the tree had been badly attacked by insects, prior to being submerged by the mire. Many trees showed signs of charring on the surface of the wood. One large *Pinus* was charred along one side, but its other side retained its bark, uncharred. However, charring on many of these trees was often difficult to identify, as friable charcoal tends to drop away from wood when exposed by the digging machines. All rot hole samples that were subsequently processed from this area contained large fragments of charcoal.

On Kilham East and West, there were extensive tree remains, rooted within the sand and very well humified, black, amorphous, basal peat. These included *Betula* and *Pinus* remains *c.* 10-40 cm above the basal sands (Plates 4.3b). In this location, about 85-90 % of the trees were *Pinus*, and the remaining ones were *Betula.* The trees were of similar size to those at Tyrham, although they were not as well preserved (this may have related to exposure, since these trees had been excavated *c.* 6-12 months previously, whereas the Tyrham trees had just been excavated by the milling machines). Signs of burning were evident, although some was distinctly unusual, such as charring beneath the root system (see Plates 4.4a, b; 4.5a).

A feature of many of the *Pinus* stumps observed across the Moors was the "ripped" nature of the stumps, with "jagged" edges, as illustrated in Plate 4.5b. Such evidence would be consistent if the base of trees had become "disconnected" from their trunks by deterioration and rotting. The author noted a very similar feature when visiting a raised mire in Ireland, where *Pinus sylvestris* had been recently burnt (Plate 4.6a, b). This feature was particularly marked in areas at Kilham West and East Ash Dump, sections 1 and 2, but not evident amongst the Tyrham Hall *Pinus*.

Elsewhere, trees appeared to have been patchily distributed across the developing mire. Remains within basal deposits were fairly common across the site, although the trees may have been growing at different periods. There was at least one other period after peat initiation when *Pinus* occupied areas of the site. This was indicated by the presence of tree macrofossils within the peat stratigraphy at Kilham East, where additional tree macrofossils were preserved *c.* 120-130 cm above these basal *Pinus*. There was a strong correlation between the occurrence of sand dunes and the distribution of *Pinus* and *Betula* remains, particularly on Kilham East, Packards North sections 1 and 2. Most of the trees were small compared with those from Tyrham Hall Quarry and Kilham West, and had wide and weak rooting systems. Sand and gravel deposits protrude through the peat in areas close to Lindholme Island, on Packards North, section 2. Here also, there were more fossil trees that showed signs of charring.

4.2.3 *Evidence for fire and human activities*

No artefactual evidence for human activity was found. The evidence for charring was widely distributed across Hatfield Moors (*contra* Dinnin, 1997c), mapped in Figure 4.1. No evidence was found to link any of the charring to the activity of humans (e.g. cut marks upon the tree remains or evidence for forest management). There was a close correlation between the distribution of the *Pinus* trees and charring. Substantial charring was noted associated with the Tyrham *Pinus*. However, none of the sections observed during the survey, or in subsequent surveys (Dinnin, 1997c), contained multiple charcoal horizons.

4.2.4 *Evidence for mire genesis and development*

Although many sections across the Moors were examined, very little stratigraphic evidence for fen peat was encountered, representing a rheotrophic phase on Hatfield Moors. An exception was the area excavated for sampling on Packards South (HAT 4, see section 4.7), where the remains of *Phragmites* were noted in the basal deposits. Elsewhere, the basal deposits were characterised by amorphous black, very well humified peat, containing abundant mineral material, sometimes with *Eriophorum vaginatum*, often including *Betula* and *Pinus* remains. There was little indication of a "forest" soil (grey, silty peat containing rootlets and wood remains) or of brushwood peat layers (very "loose" peat, composed of branches and trunks of *Betula* and *Alnus* [Smith, 1985]), which have been observed on Thorne Moors (*cf.* Buckland, 1979; Smith, 1985; Whitehouse, 1993; Dinnin, 1994), although during sampling at HAT 4 brushwood peat was noted. In most cases, *Sphagnum* peat appeared to have formed directly above the nutrient deficient sands.

4.3 Sampling strategy

Several suitable sampling locations were identified as result of field survey on Hatfield Moors as well as visits to Thorne Moors and Hayfield Lodge Farm, Rossington. Sites were selected on their ability to address the site-specific research questions outlined previously.

The sampling strategy followed several rationales. The first one was to obtain, where possible, long temporal sequences (except for bulk samples), which were capable of addressing the research questions. Secondly, on Hatfield Moors, sampling was carried out at different locations across the Moor. It was hoped this approach would provide a good temporal resolution across the site, and elucidate mire genesis and past vegetation spatial variability. Since fossil insects often produce very local pictures of environmental change, it was hoped this approach would highlight the usefulness or otherwise of taking multiple cores/samples across the same site. This is the first example of this approach in palaeoentomology, where usually just one exposure per site is sampled. Such an approach has long been practised in palynology, which has highlighted the dangers of reliance upon single profiles (Edwards, 1983; Smith, 1985; Whittington *et al,* 1991).

Figure 4.2 shows the position of all sampling sites on Hatfield Moors. In order to examine the nature of Lindholme Island, in the middle of Hatfield Moors, samples were collected as close as possible to the island (**LIND B**). The area of south Hatfield contained peats that were supposedly largely uncut, possibly extending the palaeoecological record into the medieval period. The peats also provided an opportunity to study mire initiation in this area; a sequence as long as possible was selected for sampling (**HAT 4**). Bulk samples were removed from rot holes associated with *Pinus* and *Quercus* trees exposed at Tyrham Hall Quarry, on the south-western side of Hatfield Moors in order to investigate the dead wood invertebrate communities (**TYRHAM**). On the northern part of Hatfield Moors, Kilham West, there were also many tree macrofossils and a sequence from this area was sampled. This was to examine peat initiation and the nature of the woodland in the basal peats of this location (**HAT 3**). A further sequence was also identified to the south-east of this location, on the present edge of the Moors (**LIND A**). Thus, a range of sites, spread geographically across the Moors was selected for analysis, examining the centre as well as the periphery of the present area of Hatfield Moors, although the area does not represent the former full extent of the site (see for instance the OS map for 1853, Figure 7.4). It was hoped that the samples selected would represent some of the diverse range of environmental conditions that formerly existed across the site.

On Thorne Moors, considering previous studies (Buckland, 1979; Smith, 1985; Roper, 1993, 1996; Whitehouse, 1993; 1997a), just a single location was sampled. This was to study the transition from the early *Quercus*- to *Pinus*-dominated forest. Accordingly, a location on Goole Moors, along Blackwater Dike was selected, where an exposed section contained the remains of a large *Quercus*, succeeded by a layer of *Pinus* and *Betula* macrofossils (**GOOLE Q/P**). Figure 4.3 shows the location of the site sampled (site D), together with details of all the other palaeoecological sites from Thorne Moors.

At Hayfield Lodge Farm, Rossington, an extensive floodplain sequence associated with the river Torne located within an archaeological landscape was sampled (Figure 4.4). Mather's (1991) palynological work from the same area had suggested that detrital peat deposition had commenced during the early Holocene. It was hoped that the sequence would provide a palaeoentomological record for the earlier part of the Holocene. Identified insect material (but not analysed) from Misterton Carr, a floodplain deposit associated with the river Idle, was passed to the author by P.J. Osborne, after his retirement from the Department of Earth Sciences, University of Birmingham (Figure 4.5a and b). The floodplain deposits offered the opportunity to place the mire assemblages within a regional context, and to elucidate wetland development off the margins of the bogs. Buckland and Smith (*in press*) suggest that the processes of wetland development on the floodplains and on the mires may be inter-connected.

4.4 Sample collection

Samples were recovered from an exposed section. Sections were cut back and cleaned prior to sample removal to ensure that no contamination, exposure to oxidation or fungal decay had occurred. Where possible, sections were cleared downwards until the underlying substrate was revealed. To minimise taphonomic problems, the top 10 cm (or more if there was obvious contamination) of peat was discarded as a precaution against mixing and contamination from burrowing animals. Samples were removed in 5 cm thick contiguous slices (except where otherwise indicated), following stratigraphic changes where possible, sealed in polythene bags and kept in cold storage until processing. Stratigraphic descriptions were made of all sampled sections.

4.5 Site data

Each of the following descriptions provides information on the sampling sites chosen. The stratigraphy of each site is illustrated, together with information on the location of the samples identified, and any associated dating.

4.6 Hatfield Moors, Kilham West, (HAT 3). NGR: SE 700 075.

There were many well-preserved remains of *Pinus* and *Betula* in this area (Plate 4.7). There was no surface vegetation in the vicinity and no evidence for roots or rhizomes in the upper parts of the section. Sampling was carried out along a north-south ditch cut for drainage. There were evident remains of *Pinus* and *Betula* within the profile. The depth of the excavated sequence was 103 cm. Eighteen samples (5 cm slices) were removed from the exposed peat section. The stratigraphy of HAT 3 (Figure 4.6) was recorded in the field from top to bottom; sample depths relate to the ground surface in May 1995.

4.7 Hatfield Moors, Packards south, (HAT 4). NGR: SE 691 050.

The section was close to the margin of the milling fields, on Packards south, close to the SSSI boundary that encloses a re-vegetated cut-over area known as Poor Piece. There was no surface vegetation in the vicinity and no roots or rhizomes in the upper parts of the section. A section on an east-west ditch was cut back. The depth of the excavated sequence was 155 cm. Twenty-nine samples (5 cm slices) were removed from the exposed peat section. The stratigraphy of HAT 4 (Figure 4.7) was recorded in the field from top to bottom; sample depths relate to August 1995 ground surface.

4.8 Lindholme Bank Road, Hatfield Moors.

The opportunity to remove insect samples at this location originated from a trench excavated along Lindholme Bank Road, Hatfield Moors, approaching Lindholme Island. Kelt UK, who were laying a gas pipeline along the length of the road, excavated the trench, and funded the analysis of the material from Lindholme B. Sampling was carried out in September 1994. Two sampling opportunities were identified, one on the margins of Hatfield Moors (Lindholme A) and another halfway along Lindholme Bank Road, as close as possible to Lindholme Island (Lindholme B).

4.8.1 Lindholme A, Hatfield Moors (LIND A); NGR: SE 693 069

The open section provided an opportunity to examine material not otherwise available, on the current edge of Hatfield Moors. There was a reasonable depth of peat (*c.* 130 cm). Most of the material comprised dried-out peat which initial inspection suggested might not yield any insect fossils, although this turned out not to be the case. Seven samples (5 cm slices) were removed. The stratigraphy for LIND A was recorded in the field from top to bottom (Figure 4.8); sample depths relate to the ground surface in September 1994.

4.8.2 Lindholme B, Hatfield Moors (LIND B); NGR: SE 698 068

The location of the site was 600 m along Lindholme Bank Road, on the northern side, approaching Lindholme Island from Hatfield Woodhouse (Figure 4.2). The contractor excavated a narrow trench for the purpose of laying the pipeline. The trench was deepened to a depth of 1.72cm, but it was not possible to deepen it further due to Health and Safety Regulations. At least 65 cm of peat remained below this level. A series of 18 bulk samples was removed (5 cm slices), except for the top three samples that were removed at 10 cm intervals. Details of stratigraphy were recorded in the field (Figure 4.9).

4.9 Tyrham Hall Quarry, Hatfield Moors, (TYRHAM); NGR: SE 689 062

This sampling location was accessed through the sand and gravel quarry at Tyrham Hall Quarry, on the southwestern side of Hatfield Moors, presently mined by Tilcon Plc. The sampling location is indicated in Figure 4.2. Bulk samples were removed for fossil insect analysis. At the same time, samples were removed for dendrochronological dating by Boswijk (1998).

4.9.1 Sample contexts

Tilcon 1 - *Pinus sylvestris* rot hole.

Tilcon 2 - A & B - These samples came from two holes associated with a *Pinus*. Sample A came from a rot hole (Plate 4.8a), with no signs of charring. Sample B came from a branch hole. This deposit also contained sand, possibly from when the tree had collapsed, presumably after death, with force into the underlying sands.

Tilcon 3 - Interior of *Pinus* trunk, very dry material, no charring visible.

Tilcon K - *Pinus*. This tree was dendrochronologically sampled (THQ 12), but could not be dated.

Tilcon Oak - This *Quercus* was dendrochronologically sampled (THQ25) and dated to 3618-3418 BC.

4.10 Goole Moors (Thorne Moors), Blackwater Dyke, (GOOLE, Q/P): NGR: SE 728 173.

To find a representative sequence covering the *Quercus* to *Pinus* transition on Thorne Moors, a number of field ditches and dikes were investigated, until the site along Blackwater Dike was identified (Plate 4.8b). The site, just over 100 m from Smith's (1985) GLM2 pollen site (Figure 4.3), consisted of a large *Quercus*, stratigraphically succeeded by remains of *Pinus* and *Betula*. Boswijk (1998) took a dendrochronological sample of the *Quercus*. A peat depth of *c.* 127 cm was exposed, to the underlying Lake Humber clay/silts. Twenty contiguous samples were removed (5 cm slices), as well as three bulk samples from the vicinity of the *Quercus* and *Pinus*. The top 23 cm of the sequence was not sampled, due to contamination of the upper peat. The stratigraphy was recorded in the field from top to bottom (Figure 4.10); sample depths relate to the ground surface in July 1995.

4.11 Hayfield Lodge Farm, Rossington. NGR: SK 634 998.

In 1995, land immediately south of the River Torne was developed as a sport fishing centre at Hayfield Lodge Farm. The construction work entailed the removal of fen peat (*c.* 3-4 m deep) to allow the extraction of the sand and gravel lying beneath. The succession provided the opportunity to sample a long floodplain sequence (3.6 m in depth) (Plate 4.9a, b). Substantial alluvial deposits (60 cm) overlay the fen peats. The top 120 cm of the sequence consisted of disturbed sand deposits inter-bedded with thin bands of peat, which was not sampled. Sampling commenced at 120 cm continuing to 340 cm, removing a total of nineteen samples in 10 cm contiguous bulk samples. The remains of *Quercus* and *Pinus* were noted in the stratigraphy and there was one evident charcoal layer (Plate 4.10). Field stratigraphy was recorded from top to bottom (Figure 4.11).

4.12 Misterton Carr. NGR: SK 728 950

Misterton Carr, on the River Idle floodplain, was investigated as part of excavations carried out on a series of Mesolithic flint scatters in the vicinity of Misterton Carr Farm (Buckland and Dolby, 1973). The scatters were distributed alongside the pre-1620s channel of the River Idle. The site of a former Mere on the River Idle floodplain was exposed during excavation at one of the sites (Site I). P.J. Osborne undertook sampling of this 2.2 metre peat deposit. Samples were removed as 5 cm contiguous bulk samples from a 2.20 m peat deposit (Buckland and Dolby, 1973). Flooding of the fen is indicated by a clay horizon towards the top of the sequence (0.25 m), overlain by further peat. A stratigraphic section of the site at Misterton is published (Buckland and Dolby, 1973), reproduced in Figure 4.12.

4.13 Success of the sampling strategy

The sampling programme across Hatfield and Thorne Moors provided a total of 78 and 23 samples respectively, from a number of locations across the Moors, proving a good temporal and locational spread of material. Additional sampling at Hayfield Lodge Farm provided 19 floodplain samples, which together with the 6 samples from Misterton Carr provided a good range of comparative material.

CHAPTER V: ANALYSIS OF THE FOSSIL INSECT MATERIAL, WITH PARTICULAR EMPHASIS ON A NEW METHODOLOGICAL APPROACH.

5.1 Processing for palaeoentomological remains

All samples were subjected to the standard paraffin flotation method devised by Coope and Osborne (1968). Where possible, three litres from each sample were processed, making note of additional information (see Appendix C). Where samples contained high amounts of *Sphagnum* and other mire plant material, a new approach was adopted. Peat, particularly when unhumified, is a problematic medium from which to extract insect remains. Plant remains, especially *Sphagnum*, tend to expand and float with the addition of water and paraffin, creating vast flots of plant remains (often several litres). To minimise the amount of plant material to be sorted, an additional step was incorporated into processing. During the rinsing stages, prior to flotation, two separate sieve mesh sizes were utilised (2 mm and 300 µm) one above the other. This enabled separation of the "thinner" from the "thicker, matted" fraction of plant remains. Each fraction was then processed separately. Flots were left for several weeks (covered) to encourage some of the heavier plant material to drop to the bottom of the bucket. Separation of the two fractions enabled more effective and faster sorting of material, as flots were more homogeneous. In addition, separation of the fractions stopped the finer sieve mesh from becoming "clogged" and abrading insect remains.

However, this technique was only partially successful: many flots consisted of several litres that were then sorted under a binocular microscope. A glance at the flot figures (Appendix C) will indicate the amount of sorting required to obtain assemblages from peat. However, the time invested in processing was rewarded by assemblages with an excellent level of preservation and diversity.

5.2 Preservation of the fossil insect material

As with other types of organic material, insect remains are very susceptible to desiccation; however, preservation of much of the material was excellent. Preservation was calculated by reference to the six-point scale *Preservation Index* (Roper and Whitehouse, 1994), shown in Table 5.1. The *Index* provides a general estimate of preservation conditions and an evaluative method to compare samples and sites. A recent paper by Kenward and Large (1998) discusses a new system to assess levels of erosion and fragmentation in insect fossils. The authors argue that the *Index* devised by

Roper and Whitehouse (1994), although a useful scale in general terms, suffers from a lack of precision, since it fails to examine erosion and fragmentation properties separately. The new system Kenward and Large (*idem.*) propose *is* more sophisticated and attempts to address some of the limitations of previous scales. In the light of this work and their comments, it is acknowledged that this new system offers much potential. Nevertheless, it is felt that the *Index* provides a valid guide to levels of preservation, although not as comprehensive as Kenward and Large's (1998).

Most of the material ranged between 3 and 4 on the *Index* (moderate and good), with the majority of fossils scoring 4 or more (see Appendix C for sample scores). There was a direct relationship between the peat type and levels of preservation. Fossil insects from fen peats, such as those from Hayfield Lodge Farm, were in excellent condition, as were those originating from unhumified *Sphagnum* peat. Some of the material from rot hole contexts was in exceptional condition, with many specimens wholly intact, apart from antennae. In contrast, less well preserved material originated from the very well humified, amorphous and structure-less peat that characterises the basal deposits on Hatfield Moors, suggesting that chitin corrosion occurred during peat humification.

The material from Misterton Carr was originally well preserved (*c.* 4 on the *Index* scale). This was evident from the small portion of material that had been mounted on slides. Unfortunately, the majority of the fossils had been stored in alcohol, which allows only short-term preservation. Consequently, much of the chitin had corroded until it was translucent and unidentifiable. In view of this, no further identification of this assemblage was carried out and the environmental reconstruction was based entirely upon the Coleoptera list provided by P.J. Osborne.

5.3 Identification of Palaeoentomological material

There were no significant identification problems, due to the good levels of preservation and low fragmentation (apart from Misterton Carr samples, noted above). Good levels of preservation facilitate the process of identification, because diagnostic features are more evident and a variety of different sclerites survive (e.g. head, thorax, and elytra). Since identification is often made to species on the basis of a particular diagnostic feature, the occurrence of different sclerites increases the chances of secure species-level identifications. Overall, fragments identified to this level provide information which enable fuller palaeoenvironmental reconstructions; genus level identifications provide less useful environmental information.

Identification of the fossil Coleoptera was carried out using taxonomic keys and modern Coleoptera reference collections at Sheffield University, Doncaster Museum, Manchester Museum, the British Museum (Natural History) and the Zoological Museum Invertebrate Collection, University of Oulu, Finland. Identification was always confirmed through reference to a named specimen. Help was sought from other Coleopterists (principally, Peter Skidmore, formerly of Doncaster Museum and Colin Johnson, Manchester Museum). Sclerites were recorded on a count sheet, making note of which body part was recovered. Problems associated with the identification of consistently difficult taxa as well as particular species are discussed in Appendix D.

Samples contained other insect orders (e.g. Diptera, Chironomidae, and Formicidae). Their presence was recorded on a presence/absence basis together with other associated data and are tabulated within Appendix C. All fossil insect material will be permanently stored at Doncaster Museum.

5.4 Taphonomic problems

Two considerations require consideration with regard to the entomofaunal assemblages. The first relates to the depositional environment. An important indicator of the depositional history of fossils is their state of preservation. This can provide clues, amongst other things, of differential preservation, separate origins of ecological components and episodes of dehydration (Kenward and Large, 1998). Material from both mires show very good levels of preservation and low fragmentation, which suggest that the material represent *in situ* death assemblages. There are also few indicators of erosion associated with drying-out of the deposits, despite on-going drainage. On the mires, there are no evident watercourses, which could have transported allochthonous insect material, although small peaty streams, particularly on the edges of the developing mires, may have introduced small components into the assemblages.

In contrast, the assemblages from the floodplain deposits probably contained both autochthonous and allochthonous elements. Sand layers within the peat deposits at Hayfield Lodge Farm indicate that the area was periodically flooded by the river Torne. This would have deposited and eroded material. It is thus important to consider that both floodplain assemblages from Hayfield Lodge Farm and Misterton Carr are likely to contain local as well as non-local faunal components. However, the preservational state of many of the fossils is good, which suggests that such episodes had a minimal impact upon the composition of the faunal assemblages. It also suggests that little post-depositional erosion had occurred from drying-out of deposits.

5.5 Analytical methods

The insect assemblages were analysed using a new system of ecological groupings, which enabled the data to be more readily examined and interpreted. Results from appropriate sequences were displayed using the programme TILIA (Grimm, 1991). This is a new method for grouping and displaying Coleopteran data. Problems associated with such an approach include the subjective nature of selection, assignment and interpretation of categories. In recognition of this problem, the data were also examined in the normal, descriptive manner and transformed into diversity indices for comparative interpretations.

Additional analyses were performed on the mire assemblages. Jaccard's *Index of Similarity* was utilised to assess faunal heterogeneity across the Hatfield Moors sites and samples. This test was also used to ascertain if multiple site analysis was justified as a methodological approach.

Due to the complexity and range of data from Thorne and Hatfield Moors, available because of past (Buckland, 1979; Roper, 1993; Whitehouse, 1993) and current research, the application of a multivariate ordination technique was considered appropriate. Correspondence analysis (CA) was utilised to explore similarities between sites and samples and examine the frequency and association of common species (Gauch, 1982).

5.6 The ecological classification system

5.6.1 Classification systems: problems and potential

As Kenward (1976, 1978) has pointed out, there are several problems to overcome when interpreting fossil insect assemblages. Firstly, it is necessary to determine the ecological requirements of species recovered and secondly to estimate the relative abundance and extent of the implied habitats. Both these problems are constant within any palaeoentomological study. As a method of addressing some of these problems and as an aid to interpreting the results obtained from this research, a classification system was devised. Classification systems, which attempt to group species, have been devised by entomologists (*cf.* Elton, 1966) and palaeoentomologists (*cf.* Kenward, 1978; Robinson, 1991; Kenward and Hall, 1995; Roper and Whitehouse, 1997). Previous classifications devised by palaeoentomologists were, in general, devised to examine archaeological assemblages. Kenward (1978) first suggested the use of ecological groupings to aid the identification of urban insect assemblages. However, as Robinson (1981a) has pointed out, whilst such a system appears to work well for urban assemblages, where very local conditions are being reconstructed, this system did not exploit the full potential of rural deposits. This is because the aim with rural deposits will usually include a study of environmental conditions in the surrounding landscape, away from the archaeological deposits (Robinson, 1981a). Robinson (*idem.*) devised a new series of categories, which he subsequently refined (Robinson, 1991, 1993). However, for this study, it was considered that these categories were too limiting, and that useful trends in the data could be identified by using a more sophisticated categorisation system.

Elton (1966) was the first entomologist to attempt a classification system. He pointed out that classifications are often based upon vegetational habitats but do not take into account the fact that details of plant associations are frequently difficult to apply. Structural diversity is as important, if not more important, than the plant species composition of the community within which the insects find themselves. Many aspects of habitat structure and particularly some forms of dead organic matter are essential to understanding animal habitats. Very few of these habitats are closed systems, a fact that makes classification harder (Elton, 1966).

Before proceeding onto a discussion of the classification system itself and its development, there are a number of points that require consideration. The division into categories is essentially an interpretative tool and suffers from certain limitations. For instance, it takes no account of the uneven quality of ecological information for the different insect groups or the regional variation in the ecology of species. In some cases, the ecological requirements of species are unclear or change according to geographic location. Host specificity generally increases towards the limits of the insects' range (Allen, 1956), so records between Continental Europe and Britain may be different. In addition, at different stages of an insects' life cycle, a single species may fill various ecological niches within a single habitat-type or occur in widely different habitats. Many insects will hibernate under the loose bark of dead wood, whilst spending the rest of the year in wetland habitats (Elton, 1966). This is compounded by a general ignorance about the biology of many species. Because of these problems, the apportioning of species to categories can be a subjective process. However, every attempt was made during this research to maintain as much objectivity as possible during classification.

More generally, classification takes little account of the fact that the majority of species are often rare, while a number are moderately common, with the remaining few species being very abundant (Magurran, 1988). Classification is carried out at *ecological habitat* rather than *ecological niche* level, so it is not possible to account for the fact that certain ecological habitats contain more niches than others, with varying population-carrying potentials. This is because a species will inhabit its own particular ecological niche, which supports that species and species population (Colinvaux, 1993). Thus, some habitats are able to support a wider range of species than others; different species will also occur at different population densities, some being abundant, some rare, depending upon the carrying potential of a particular ecological niche (Colinvaux, 1993). Classification also takes little account of the different dispersal abilities of species. Such abilities may depend upon whether species are winged or not, availability of suitable habitat and threshold temperatures. For instance, persistent cold winds can limit the dispersal of emergent beetles (Szujecki, 1987). Finally, although ecological groups attempt to examine *community structure*, it is more often limited to *community content* (O'Connor, 1998).

Despite these problems, a community approach, utilising ecologically related groups of species to determine the past existence of their habitats is still a promising approach (Kenward, 1978). Classification provides a "panorama" which allows the ecologist an understanding of how particular habitats "fit in" with others and how their communities interact (Elton, 1966). Most importantly, this technique should be used to isolate trends within groups, rather than compare habitat values. Numbers of particular habitat *indicator species* should not be taken to indicate direct proportions of associated habitat.

5.6.2 The classification system

Using a two tiered system of classification, each species was firstly categorised into a larger (first tier) category, the *habitat system* (this may be represented by a landscape system or type/niche, e.g. "woodland", or a non- or pseudo- vegetational system e.g. "aquatic" or "rotting vegetation"). Nested within each habitat system are associated *macro*-and *micro-scale habitats* (second tier). Within this second tier, where possible, an attempt was made to consider habitat structure. Table 5.2 displays the full classification system. Each habitat category is prefixed by an identifying code number.

Classification underwent a number of stages. Firstly, *eco-codes* for all the species were studied. These codes were devised by the entomologist Koch (1989, 1992) and form part of a three tiered classification system which attempts to examine ecology, habitat type and habitat range for Coleoptera species. Originally, the intention had been to utilise the eco-codes for the classification of the results. However, it was soon evident that Koch's system was inadequate for the purposes of palaeoenvironmental reconstruction. Firstly, Koch's eco-codes are based upon central European data, which can sometimes be contradictory with British data. It was also found that the coding was inconsistent. Finally, some of the categories had little useful palaeoecological meaning (e.g. categories such as "under bark" or in "wood litter" are not very useful; in contrast, categories such as "under coniferous rotting wood" are more meaningful).

A new system providing more meaningful categories was devised. The eco-codes were used as starting point, but were substantially modified. *All* available ecological data, both British and European, were considered. Anthropogenic activities, which may have affected the distribution and choice of hosts of British species, were also considered when assessing the ecological preferences of species. Key words that were thought to summarise species' ecological preferences were selected. All species were then considered together to enable an overview of the different habitat types represented. A preliminary list of classes was then drawn up and each species re-checked against this list, allowing amendments and additions to categories. The system enabled all species to be satisfactorily classified.

It is hoped that the system may be used for future research. It has the advantage in that it can be "expanded" to accommodate other habitats presently un-represented. A total of 39 categories were devised, grouped under 8 main habitat systems:

1. **Woodland and trees;**
2. **Damp woodland**
3. **Heath and grassland**
4. **Non-acid wetlands**
5. **Acid wetlands**
6. **Hygrophilous ("wet loving")**
7. **Aquatics**
8. **Decaying debris**

Each of these systems was subdivided into more specific categories. Species which could not be classified (e.g. specimens identified to genus or family only) were categorised as "Unclassified". An additional category for species attracted to fires was also devised, although such species also belonged to one of the main habitat system groups. Ecological information was obtained from a variety of sources, provided by the Coleopteran habitat data-base BUGS (Sadler *et al.*, 1992), maintained by Prof. P.C. Buckland, University of Sheffield.

5.6.3 The categories

It is worth discussing some of the categories in some detail, although Table 5.2 provides information on the types of species assigned to each group.

Considerable difficulties were encountered in the separation of the acid-loving from the non-acid loving species, since it is often unclear from the literature whether some aquatic species are acid-loving or not. This is clearly an important distinction when attempting to examine the different stages in mire development. Foster (1995) suggests that some species are acid tolerant, rather than acid-loving: many aquatics considered acidophilous continue breeding in calcium-rich habitats. Such species may have a *tolerance* for poor nutrient status and a dependence on a soft organic substratum. Less tolerant species are not present to compete with these species and there may be less predators, allowing the population to thrive, even if the bog habitat may be sub-optimal or put some species under stress (Brooks, 1997). The separation of acid loving/tolerant species is thus not straight-forward. Relatively few studies have examined the full environmental conditions associated with many of these aquatic species. Likewise, it is difficult to differentiate between the true terrestrial ombrotrophic-loving species from those that also appear on a range of other sites. Thus, species such as *Pterostichus diligens* and *P. nigrita* are found across a wide range of habitats, although the former is more numerous on more nutrient-poor sites (Holmes *et al.*, 1993). These species have been placed within the non-acidic bogs/wetlands rather than acid bogs category, although it could be argued that the former species is at least acid-tolerant.

Some categories overlap, in particular the moorland/heathland and acid wetland categories. The former is a much drier ecosystem and often associated with sandy substrates. Mires, on the other hand, are wetland ecosystems, although they share many vegetational communities with heaths, including dwarf shrubs like *Calluna vulgaris* and *Empetrum nigrum*, along with a range of other herbs and bryophytes. The two ecosystems are perhaps best seen as containing many similar elements, but lying at different ends of a wetness gradient. For the purposes of categorisation, insect species that feed upon *Calluna vulgaris* were placed in the heathland category. Although also characteristic of acid mires, this plant is normally found in drier situations, preferring better-drained habitats. In contrast, the acid-wetland category contained species associated with raised mire, particularly with *Sphagna*.

5.6.4 Analysis

Analysis was calculated based on numbers of individuals recovered, rather than number of species (*cf.* Robinson, 1991). There has been some debate as to the validity of utilising numbers of individuals versus numbers of species when attempting to examine environmental trends within samples (Jordan, 1995). Basing categories upon numbers of individuals poses difficulties due to the fact that some species are common and will occur in abundant numbers, whereas others are rare and occur in low concentrations. Using numbers of individuals recovered places undue emphasis on abundant species, although this can, to a certain extent, be rectified by excluding some categories from analysis, such as aquatic species, which form an integral part of the depositional environment (*cf.* Roper and Whitehouse, 1997). Conversely, by choosing to examine the composition of the samples at species level, sample size decreases numerically, affecting the statistical significance of the results, and overemphasises the importance of samples with a low diversity of species and individuals. Some species may be adventitious, and this approach can bias samples more heavily towards such elements.

Within the samples from the Levels, there are generally very few superabundant species. Where these occur, they are highlighted within the relevant section. In many cases, species are often represented by few individuals. Utilising numbers of species rather than numbers of individuals tends to decrease sample sizes, making results more likely to be affected by spurious factors. In addition, it is customary within the discipline to take numbers of individuals within analysis, rather than numbers of species (e.g. Kenward, 1978; Robinson, 1991, 1993), so this was the approach taken.

5.6.5 Presentation of the palaeoentomological data

Results of the classifications were displayed using the palynology programme TILIA (Grimm, 1991). It should be emphasised that in this context, the diagrams are a method for displaying trends from palaeoentomological data and they are not meant to be viewed as pollen diagrams.

The most obvious difference is the fact that the diagrams display counts rather than percentages. Initially, both percentages and raw count diagrams were devised. Little difference was evident between the two diagrams, except that the percentage diagram occasionally showed increases in categories that were the products of increases/decreases elsewhere, rather than reflecting changes in environmental conditions represented. *All* Coleoptera were identified and counted (rather than a proportion) so it would appear sensible to use absolute numbers. Sample sizes were all consistent, although the period represented by a sample, may, of course, be variable, since this is determined by the rapidity of peat deposition. Increases in numbers of individuals are more likely to reflect actual ecological changes. Problems associated with the unevenness within insect populations discussed previously would be further complicated by the use of percentages: actual counts at least provide a realistic estimate of the numbers of individuals involved. Finally, counts provide some idea of fluctuations of the numbers of individuals representing different habitats, but they do not indicate the actual contribution each habitat category makes to the landscape being studied: the display of actual percentage could be temptingly interpreted in such a manner.

Previous researchers have attempted to obtain arable/pastoral ratios from Coleoptera (*cf.* Robinson, 1983) although the results were only able to show the relative importance of each habitat. Of greater concern, percentages of wood-loving species have been taken to indicate particular amounts of woodland cover. For instance, Robinson (1991) suggests that a figure of 7% of wood and tree dependant species is indicative of over one-third woodland cover. However, the lack of taphonomic studies dealing with the dispersal of wood-associated insects, coupled with effects of the individual and particular circumstances surrounding the formation of each fossil assemblage casts doubt on the reliability of such estimates (Roper and Whitehouse, 1994).

Whilst pollen data are usually sampled (and displayed) at a high resolution, palaeoentomological data are at a much coarser sampling resolution (5-10 cm bulk samples in this case). Thus, each point on the diagram actually represents 5 cm of deposit, although it is displayed as though representing 1 cm of deposit. The basal depth of each sample has been used as the sample level on the TILIA diagrams (because of this problem, a lithology has not been displayed adjacent to each diagram, as there is no direct relationship between the point represented by the sample and stratigraphy. These relationships have all been previously displayed in Figures 4.6- 4.12). Diagrams were zoned using CONISS, but some zones may only contain a single counted sample due to the coarser sampling associated with palaeoentomological samples. The zones indicate extrapolated trends from the data available.

Not all samples could be displayed using TILIA (e.g., where samples did not form part of a succession). Simple graphs using Microsoft Excel were used to display these results.

5.7 Diversity indices

The intrinsic variability of a sample can be measured quantitatively by determining the number of different species and their abundances in the samples (i.e. species diversity). Diversity consists of two components: firstly, the variety and secondly the relative abundance of species (Magurran, 1988). Measures of diversity are regarded as indicators of the well-being of ecosystems (Magurran, 1988), although many specialised ecosystems (e.g. ombrotrophic bogs) have low species diversity, but with high species rarity. Diversity is therefore only of value when it is used to compare like habitats.

There is little consensus upon the most suitable diversity measure index (Magurran, 1988). Magurran (*idem.*) suggested that the log series index, α, because of its good discriminant ability and the fact that it is not unduly influenced by sample size, is a satisfactory measure of diversity. Its only disadvantage is that the index is purely based upon S (species richness) and N (number of individuals), so it cannot discriminate situations where S and N remain constant, but where there is still a change. However, it is unlikely that data collections will behave in this way (Southwood, 1978). Southwood (1978) concluded that the satisfactory performance of this index across a wide range of circumstances make it an ideal candidate as a universal diversity statistic. Fisher *et al.* (1943) proposed the first and most durable of the α indices (Southwood, 1978).

Fisher's alpha (α) has the advantage of being independent upon sample size, since α is an intrinsic property of the population (Fisher *et al.*, 1943). This has evident advantages in palaeoecological assemblages, where sample size may vary or where peat of different humification levels is being examined (samples may represent different temporal scales, according to the speed of peat deposition) and is particularly suited to assemblages subject to many random variables. A number of entomofaunal studies have utilised this diversity index, including modern work on Thorne and Hatfield Moors (*cf.* Ball, 1992; Heaver and Eversham, 1991) and several palaeoentomological studies (*cf.* Kenward, 1978; Roper, 1993; Hill, 1994).

For all the reasons cited above, Fisher's α was selected as an analytical tool. The diversity index for all samples was calculated using the minimum number of individuals and species in each sample, using the nomogram scale published by Fisher (1944).

5.8 Jaccard's coefficient

A different question which might be asked of a data set might be how species numbers and identities differ between communities or along environmental gradients (Magurran, 1988). Beta (β) diversity is concerned with the change in species diversity from habitat to habitat and the comparison of the quantitative and qualitative make-up of different communities: in other words, some measure of difference (or similarity) (Southwood, 1978). Within palaeoecology, such an approach can be utilised to examine the differences between samples within the same site, (which represent different communities) and different sites (a comparison along an "environmental gradient").

The easiest way of measuring the β diversity of pairs of sites is with similarity coefficients. A coefficient of similarity can measure the extent to which two habitats (or sampling sites) have species or individuals in common. There are a vast range of similarity indices available (Magurran, 1988). In entomofaunal studies, the most widely used are the Jaccard and Sørensen coefficients (Jaccard, 1912; Sørensen, 1948). Jaccard's coefficient was chosen to analyse the samples from Hatfield Moors since this appears to be the most widely applied similarity coefficient reported within the ecological and palaeoecological literature (e.g. Butterfield and Coulson, 1983; Perry *et al.*, 1985).

The coefficient was calculated as follows (after Southwood, 1978):

$$\mathbf{C_J = j/(a + b - j)}$$

where **j** = the number of species common (joint) in both sites/samples and **a** and **b** are respectively the total number of species in each sample. The index is equal to 1 in cases of complete similarity (where two sets of species are identical) and 0 if the sites are wholly dissimilar and have no species in common (Magurran, 1988). A value of < 0.5 indicates a poor relationship (Perry *et al.*, 1985).

5.9 Correspondence analysis

Very few quantitative methods have been used in the palaeoenvironmental analysis of fossil beetle assemblages, with a few exceptions (e.g. Perry *et al.*, 1985; Perry, 1987; Cong and Ashworth, 1987). All fossil insect data from Thorne and Hatfield Moors (including previous research by Buckland [1979], Roper [1993] and Whitehouse [1993]) were subjected to multivariate analysis using the ordination technique Correspondence Analysis (CA) (Gauch, 1982; Jongman *et al.*, 1995). CA produces an ordination diagram arranging sites (in this case, palaeoecological samples) along axes on the basis of species composition (Jongman *et al.*, 1995). The first axis accounts for most of the variability in the data and the second for axis most of the rest and vice versa (Jongman *et al.*, 1995). The first axis is plotted horizontally and the second axis vertically. The package used for the analysis was CANOCO (ter Braak, 1987-92), originally designed for the analysis of vegetation survey-data. The program used for plotting the results was CANODRAW (Smilauer, 1992).

CA, using CANOCO, has been used successfully in archaeobotanical research (e.g. Lange, 1990; Charles *et al.*, 1997.), but has not been applied previously in the analysis of fossil insect assemblages. Cong and Ashworth (1997) used CA to analyse a small insect assemblage, but the application is problematic (they use presence/absence of a very few species [see Jones, 1991, 64 for comments] and apply Canonical Correspondence Analysis [CCA]).

CA allows the researcher to explore how well an environmental character or variable explains the species data (Jongman *et al.*, 1995). The nature and role of these variables are often not known; when patterns emerge from the data it may be possible to relate them to environmental or other variables (Lange, 1990). Within palaeoentomology, as with many other analyses of fossil assemblages, these variables are generally not known prior to analysis. Under such circumstances, an indirect multivariate approach such as CA is appropriate as an exploratory method (Lange, 1990). Other indirect approaches are Cluster Analysis and Principal Component Analysis (Gauch, 1982).

CA uses raw counts of species data. Abundance of species is considered and, most importantly, there is no need to provide environmental data or variables. In other words, the patterns produced through CA are entirely objective since they are generated by the raw data. In contrast, other techniques such as Principal Components Analysis (PCA) cannot deal with large matrices of data and will reduce the variables used to a smaller number of components (e.g. Jones, 1987). This means that statistical tests are carried out on modified data sets. CA allows the simultaneous ordering of species and samples in the same space (Lange, 1990), allowing relationships between sites as well as related species to be explored (Jongman *et al.*, 1995). The rows and columns, which are displayed in a species list (the data matrix), can be displayed simultaneously as points on an ordination plot. To examine what best explains an environmental variable that affects a species, CA constructs a theoretical variable (eigenvector) which best explains the data (Jongman *et al.*, 1995). The final ordination scores are the co-ordinates in the first dimension of the samples' and species' space (first ordination axis) and form the first eigenvector (Gauch, 1982; Lange, 1990). The computation of the other eigenvectors allow all dimensions in the data to be defined (Gauch, 1982), constructing a second and further axes.

It is worth discussing the interpretation of the CA plots, following Lange (1990). Plots show relationships among species and samples. Species or samples which are removed from the origin of the plot (point [0,0]) in the same direction are positively associated. Samples/species most similar in sample composition/species association will be positioned closest together. Species or samples pulled in opposite directions will be negatively associated with such points. Distance from the origin dictates the degree of diversion of samples or species (Lange, 1990).

Correspondence analysis was only applied to the mire assemblages, principally to address two questions. Firstly, it was used to explore if certain species consistently occurred together and reacted to the same stimuli (e.g. moisture, acidity). It was hoped that any results might elucidate why some species of beetle have became extinct from the British Isles (e.g. some *Rhyncolus* species) as well as highlight the behaviour of raised mire specialists. Secondly, it was hoped the analysis could quantify the level of similarity/dissimilarity between assemblages from the two mires. Both Thorne and Hatfield Moors have been regarded as being very similar sites, yet much of the modern entomological work shows this is not the case (*cf.* Skidmore, 1997, *in press*). It was hoped that exploring the levels of similarity/dissimilarity between the two sites might quantify their faunal differences and perhaps elucidate their development.

A taxonomic list including all the fossil insect data from Thorne and Hatfield Moors created a list of 60 samples and *c.* 8622 MNI. In community ecology, it is usual to omit taxa that occur in less than 5%-10% of samples from a data matrix prior to multivariate analysis (Gauch, 1982, 213-4; Lange, 1990, 76; Jones, 1991). This is due to the process of reciprocal averaging which places rare taxa (and samples containing those rare taxa) at the extreme ends of ordination axes (Gauch, 1982). For this reason, it was decided that taxa that occurred in less than 5 samples (< 10% of the overall samples) should be omitted from analysis. Part of the purpose of the analysis was to examine the behaviour of common species and it was felt that rarities should not be allowed to affect the overall statistical results. This reduced the number of taxa within the analysis from 591 to 105. Despite this large reduction in the assemblage, CA was still seen as the best way of addressing the questions outlined above.

5.10 Radiocarbon dating of samples

Prior to commencement of the project, Smith (1985) had carried out a comprehensive radiocarbon dating programme of Thorne Moors as well as obtaining a number of dates for Hatfield Moors. Dendrochronological analyses of material for the Moors has also been carried out (Boswijk, 1998). However, additional dates were required to provide an accurate dating framework for Hatfield Moors and Hayfield Lodge Farm. These were obtained through the NERC Radiocarbon Laboratory, East Kilbride (Radiocarbon Dating Allocation 659/0896). One date was obtained for the base of north Hatfield (HAT 3) and eight dates for samples from south Hatfield (HAT 4). Nine radiocarbon dates were obtained from the sequence at Hayfield Lodge Farm. Two additional AMS samples from Lindholme Bank Road (LIND B) were obtained through Beta Analytic (funded by Kelt UK). An additional date was available for the base of the River Idle, at the bottom of the sequence from Misterton Carr (Buckland and Dolby, 1973). A summary of all radiocarbon dates from the Levels is displayed in Table 5.3.

5.11 Selection of material suitable for radiocarbon-dating

Olsson (1986, 434) recommends dating where possible well-defined plant remains instead of bulk sediment. Given the difficulties associated with accurate radiocarbon dating of peat samples (Lowe *et al.*, 1988; Pilcher, 1993; Shore *et al.*, 1995; Kilian *et al.*, 1995), during the rinsing phases of processing, prior to paraffin flotation, suitable material for radiocarbon dating was removed (e.g. wood/twigs and other macrofossils). From LIND B two samples of *Calluna* seeds were submitted for AMS (Accelerator Mass Spectrometry) dating. All radiocarbon material was kept in cold storage until dating. Relationships between stratigraphy, samples and radiocarbon dates have been previously indicated (Figures 4.6 - 4.12).

CHAPTER VI: PALAEOENTOMOLOGICAL RESULTS FROM HATFIELD MOORS.

6.1 Introduction

This chapter presents and discusses the palaeoentomological samples from Hatfield Moors. Details of the sampled contexts and associated stratigraphy have already been presented in Chapter 4. The results are examined site-by-site. Radiocarbon dates are presented in Table 6.1. The chronology of the palaeoentomological samples is constructed in calendar dates, due to the mixture of dendrochronological (Boswijk, 1998) and radiocarbon dates.

Coleopterous fossil remains were identified from 5 different locations across Hatfield Moors (HAT 3; HAT 4; LIND A; LIND B; TYRHAM), across 32 samples. A total of 3514 minimum numbers of individuals (MNI) were identified, across 360 species, from 42 families. The total fossil species list for Hatfield Moors is tabulated on Table 6.8, which also highlights the Red Data Book status of species (see Appendix A for details of this classification), the habitat categories to which each species is assigned to and any new fossil records. Additional information on samples processed is summarised in Appendix C and problematic identifications for each site in Appendix D.

6.2 Hatfield Moors, Kilham West, (HAT 3).

6.2.1 Introduction

Two fossil insect assemblages were analysed from HAT 3, comprising 150 MNI, belonging to *c.* 50 different taxa, across 15 families. The samples were examined to provide an insight into the basal peats of this northern part of the Moors. Whilst examining more than two samples would have provided valuable data, the two considered were deemed sufficient to answer this question and time constraints precluded any further analysis. The stratigraphic relationships between samples are illustrated in Figure 4.6. Table 6.2 tabulates the list of fossil Coleoptera.

6.2.2 Age of the deposit

A radiocarbon date indicates peat initiation in this area *c.* 3350-3030 cal. BC (4480 ± 45 BP, SRR-6119). This date corresponds well with other peat initiation dates for Hatfield Moors (Table 6.1).

6.2.3 Results

The samples from HAT 3 contain a range of well-preserved insects. Charred material was noted from both samples during processing, the size and abundance of which suggest *in situ* fire. Members of the families Carabidae, Dytiscidae, Staphylinidae, Scirtidae and Curculionidae dominate the faunal assemblage. Three non-British species are present. Figure 6.1 displays the fossil insect habitat categories represented.

6.2.4 Environmental reconstruction

The most striking difference between the two assemblages is the contrast between the number of fossils recovered from basal sample 18, compared with 17. This is particularly evident in Figure 6.1. It seems likely that the low MNI count in sample 18 is the product of taphonomic processes, as the poorly preserved nature of the assemblage suggests. The poor nature of the fossils from the humified peats could indicate a fluctuating water table. However, there are some apparent differences between the two assemblages.

6.2.4.1 The woodland community

Pinus was growing in the location when peat initiation began. This is indicated by the presence of fossil beetles which live on and in *Pinus* trees, as well as by the *Pinus*-wood preserved at the base of the section. *Hylastes ater* and the non-British *Rhycolus sculpturatus*, an *Urwaldrelikt* species (Old Forest) are associated with rotting pinewood (Palm, 1953; Alexander, 1994), although the latter is also found in deciduous trees on the Continent (Palm, 1959). *R. sculpturatus* is frequently associated with the non-British *R. elongatus* (Palm, 1953) and shares a similar habitat.

There were other tree taxa in the vicinity. Members of the genus *Rhynchaenus* feed on the leaves of various broad-leaved trees such as *Quercus*, *Fagus*, *Betula*, *Ulmus*, *Alnus*. *Hylesinus crenatus*, (sample 18) is associated particularly with the thick bark of old *Fraxinus*, attacking only dying trees (Palm, 1959). The non-British saproxylic (*"Species of invertebrates that are dependant, during some part of their life cycle, upon the dead or dying wood of moribund or dead trees, or upon wood-inhabiting fungi, or upon the presence of other saproxylics"* [Speight, 1989, 1]) *Prostomis mandibularis* is present in sample 17. This is an *Urwaldrelikt* species, which is found mainly in decayed red rotted *Quercus* wood (Horion, 1960). A *Quercus* fossil tree was found in this area during the field survey (Section 4.3.2).

Alnus carr woodland and fen communities were present. The ground beetle *Agonum obscurum* is typical of swampy deciduous woods, particularly associated with *Alnus*

(Lindroth, 1945), but can also be recovered on mossy bark of old *Quercus* (Crowson, 1962), as well as in *Sphagnum* bogs (Lindroth, 1945). The fossils may have been associated with any of these habitats. The Carabidae *Agonum fuliginosum*, *Pterostichus nigrita*, *P. minor* and *P. diligens*, are all hygrophilous species common in fen woodland and peat bogs (Lindroth 1945), suggesting fen conditions at the base of the sequence. None of the obligate tyrphobionts, such as *Agonum ericeti* (Koch, 1989), are present.

6.2.4.2 The woodland/heath and heath community

The adults of elaterids *Dalopius marginatus* and *Pseudathous hirtus* are found on herbs and shrubs in woodlands (Koch, 1989), possibly living in open areas between the trees or on areas of *Pinus* heath. *Rhyzobius litura* lives on sun-exposed woodland margins and heaths (Koch, 1989). These species were recovered in sample 17, together with other *Calluna*-heath indicators (e.g. *Bradycellus* sp., the *Calluna* feeder, *Micrelus ericae* and *Rhagonycha testacea*). Sample 18 contains no heath indicators.

6.2.4.3 The acid and non-acid component

Some species indicate the trophic state of the bog. Sample 18 contains wetland species which prefer non-acidic conditions, with a lack of species considered acid-loving (e.g. *Plateumaris discolor*). Mildly basic environmental conditions are indicated by *Plateumaris sericea*, whose larvae spin cocoons in rhizomes and roots of *Typha latifolia*, *Iris pseudacorus*, *Schoenoplectus lacustris*, *Bolboschoenus maritimus* and *Sparganium erectum* (Stainforth, 1944), as well as on *Carex* and *Nuphar* species (Bullock, 1993). *Limnobaris dolorosa* is usually found on Juncaceae and Cyperaceae, *Carex*, *Scirpus* and *Cladium* species (Koch, 1992). Both species are considered fen-loving, and are likely to be indicative of minerotrophic/mesotrophic conditions. Species associated with plant debris, such as *Cercyon convexiusculus*, which is common in fen litter (Friday, 1988) and *Olophrum fuscum* would corroborate this idea.

In contrast, sample 17 contains species which are associated with more acid conditions, such as the reed beetle, *Plateumaris discolor*. This is associated with *Sphagnum* and *Eriophorum* (Stainforth, 1944) and typical of acid raised bogs (Koch, 1992). The chrysomelid *Altica ericeti/britteni* whose larvae live on *Calluna*, *Erica* and *Empetrum* is also present (Marshall, 1980). Other species are characteristic of acid bogs, such as the two RDB 2 staphylinids *Stenus kiesenwetteri* and *Lathrobium rufipenne*, and *Ochthephilum fracticorne* which lives in *Sphagnum* litter (Skidmore, 1970; Hyman, 1992; Koch, 1989). These acid indicating taxa are mirrored by a large increase in hygrophilous species, such as members of the Scirtidae.

6.2.4.4 The aquatic community

Differences between the two samples are also evident amongst the aquatic species. Sample 18 contains fewer aquatic species, particularly those associated with acid conditions. The small dytiscid *Hydroporus scalesianus* is found in fen and carr, but it also lives in peat bogs or sedge beds at the edge of open water (Shirt, 1987). *Agabus affinis* is mostly associated with *Sphagnum*, frequently in bogs, but is also common in small forest fens (Nilsson and Holmen, 1995). Sample 17 contains a much increased aquatic fauna, with higher numbers of *Hydroporus* spp., particularly *H. gyllenhali*, *H.tristis* and *H. melanarius*, all of which are typical of acid bog pools (Friday, 1988). This increase may reflect larger areas of aquatic habitat.

6.2.5 Diversity indices

Since there are only two samples from this site, the diversity values for HAT 3 are not plotted. Sample 18 contained 38 MNI across 32 species, which gives an index value of 50. Sample 17 contained 112 MNI and 40 species, giving an index value of 24. The high diversity of the basal sample must be related to the fact that many elements of undisturbed forest were present, an ecosystem which is higher in diversity than many others (Elton, 1966; Southwood, 1978). In contrast, the diversity decline evident in sample 17 must have been caused by the onset of increasingly ombrotrophic conditions.

6.2.6 Environmental interpretation

The faunal assemblage seems to represent sandy *Pinus-Calluna* heath on the margins of Hatfield Moor, interspersed with broad-leaved trees in areas with better drainage. Besides undisturbed *Pinus* forest, there was also deciduous woodland, probably including *Quercus* and *Fraxinus* growing on the developing mire. *Alnus* may have been growing in the vicinity. There was an abundance of mature dying and dead wood, which would have been a particularly attractive habitat to some of the *Urwaldrelikt* species recovered. *Calluna* seems to have formed an under-storey beneath the *Pinus* trees, as well as in areas of more open woodland.

Minerotrophic fen conditions seem to be represented, with evidence for aquatic plants, such as *Phragmites* spp., *Carex* spp., *Juncus* spp., *Typha latifolia*, *Iris pseudacorus*, *Scirpus* and *Cladium* spp. These plants grew in the vicinity of small pools, where aquatic beetles typical of forest fens lived. The absence of detritus pond species suggests little accumulating plant debris.

There appears to have been a very swift change of trophic status at HAT 3, as the acid loving species in sample 17 indicate. Across just one sample there appears to have been a transition from minerotrophic/mesotrophic conditions to largely acid, ombrotrophic conditions. This is also reflected in the diversity indices of the two samples, which clearly indicate this environmental change. Since the succeeding samples were not examined, it is not possible to say whether conditions remained the same thereafter. Species typical of acid raised bogs associated with *Sphagnum, Eriophorum, Calluna,* and *Erica* appear, as well as those found living in *Sphagnum* litter and acid tolerant aquatics. The increase in aquatic taxa may have been in response to an expansion of the aquatic habitat, perhaps with pools becoming larger and more frequent.

The mire in this area appears to have become wetter and ombrotrophic very rapidly. The depth between the base and the top of sample 17 is about 18 cm; however, problems associated with compaction and decay of peat make the assessment of the temporal interval between these two points problematic, especially given the drawbacks associated with assessments of peat accumulation rates (e.g. Korhola, 1992). The transition from mesotrophic to ombrotrophic mire may have taken as little as *c.*200 years (based upon an average accumulation rate of 1 mm per annum), but it may have taken much longer. Both samples contained abundant charcoal remains, which suggests the remnants of an *in situ* fire and raises questions regarding the importance of fire events within *Pinus*-forest and -mire ecosystems. Neither sample contained evidence for human activity.

6.3 Hatfield Moors, Packards south, Site 2 (HAT 4).

6.3.1 Introduction

A total of 17 fossil insect assemblages were analysed from HAT 4, comprising a MNI of 1814, belonging to *c.* 260 different taxa, covering 37 families. The stratigraphic relationships between samples are illustrated in Figure 4.7. Table 6.3 lists the fossil insects recovered. Figure 6.2 shows the insect macrofossil diagram with associated habitats. faunal assemblage zones and available radiocarbon dates, and Figure 6.3 illustrates the diversity of samples from this location.

6.3.2 Age of the deposit

Some of the radiocarbon dates from HAT 4 cluster around *c.* 1300-1100 cal BC:

HAT 4 (Packards south)	3164 ± 40	SRR-6127	1.50-1.55 m	Base of peat	1520-1390 BC
	2965 ± 45	SRR-6126	1.20-1.25 m		1320-1030 BC (0.95) 1390-1340 BC (0.05)
	2890 ± 40	SRR-6125	1.05-1.1 m		1260-980 BC (0.98) 960-930 BC (0.02)
	2960 ± 45	SRR-6124	0.95-1.0 m		1320-1030 BC (0.96) 1380-1340 BC (0.04)
	3020 ± 45	SRR-6123	0.85-0.90 m		1420-1120 BC
	2960 ± 40	SRR-6122	0.75-0.80 m		1320-1040 BC (0.97) 1380-1340 BC (0.03)
	2870 ± 40	SRR-6121	0.40-0.45 m		1220-920 BC
	1405 ± 45	SRR-6120	0.10-0.15 m	Top of peat	560-680 AD

Several possibilities could explain this factor. Firstly, much of the material came from close sampling intervals, in some cases just 10 cm. apart. In many cases, the material submitted for dating (wood) came from bulk samples, rather than material taken from precise points on the exposed section. This proximity is likely to have caused problems, particularly when the error ranges are taken into consideration. Once calibrated, these ranges often amount to about 300 years. In the case of samples 23, 20 and 18 which were dated, only 30 cm separated the top and bottom of this part of the deposit, which could conceivably represent 300 years of deposition (assuming a broad 1mm per year deposition rate), although compaction and decay could mean that the original deposit was greater. These samples also appear to have been deposited at a time when the mire was becoming wetter. Peat deposition may have occurred very rapidly during this period, although the fairly well humified nature of the peat at this point may not corroborate this.

Much of the rationale behind the dating strategy was to obtain dates on horizons of interest (e.g. where particular species were present). However, in some cases this meant that samples for dating were clustered together (mainly towards the base of the sequence). In retrospect, it might have been better to obtain radiocarbon dates more evenly through the sequence, as Bennett (1994) recommends. This would have had the effect of minimising any potential errors.

Dates above this part of the sequence show an upward trend and would appear more realistic. The date for the top part of the sequence, in contrast, jumps from about 1220-

920 cal BC (2870 ± 40 BP, SRR-6121) to 560-680 cal AD (1405 ± 45 BP, SRR-6120), within 30 cm. It seems unlikely that just 30 cm. of deposit was formed over, potentially, a 1,800 year period, particularly given the unhumified nature of the deposit, which suggests rapid peat deposition. This jump in the dating sequence might be explained if peat cutting had occurred on the site sometime during this period, truncating the sequence, although this was not evident in the stratigraphy.

A chronology for HAT 4 has been developed, with all the above points in mind, based upon the available data. Calibrations for individual dates are shown on Table 6.1. Calibration has the effect of extending the date ranges and actually ameliorates the "clustering" of the dates. The period represented by insect assemblage zone 1 is roughly dated to *c.* 1,500-1,400 cal BC to *c.* 1,300 cal BC (3165 ± 40 BP, SRR-6127) (representing about 25 cm. of deposit), insect zone 2 is dated from *c.* 1,300 cal BC to *c.* 1,000 cal BC (2965 ± 45, SRR-6126; 2890 ± 40 BP, SRR-6125; 2960 ± 45 BP, SRR-6124) (representing about 30 cm. of deposit), and insect zone 3 is dated from *c.* 1,000 cal BC to *c.* 700 cal AD (3020 ± 45 BP, SRR-6123; 2960 ± 40 BP, SRR-6122; 2870 ± 40 BP, SRR-6121; 1405 ± 45 BP, SRR-6120) (representing about 80 cm. of deposit). No attempt has been made to date each of the sub-zones 3a and 3b.

6.3.3 Results

The samples from HAT 4 contain a range of very-well preserved insect fossils, across a wide range of families. Members of the Dytiscidae, Hydraenidae, Hydrophilidae, Staphylinidae and the Scirtidae are particularly well represented.

To facilitate interpretation of the insect assemblage, the fossil insect diagram has been divided into 3 zones (Figure 6.2): insect zone 1, 2 and 3, of which the latter is also divided into sub-zones 3a and 3 b. Broadly speaking, each zone follows the stratigraphic units represented at the site (see Figure 4.4). There is a good correlation between minimum number of individuals (MNI) and number of taxa in each sample (Figure 6.2), although samples 22, 20 and 18 (insect zone 2) show a particularly high value of individuals versus number of taxa. This is due to the disproportionally high numbers of MNI represented by the Scirtidae family (moss feeders), which represent 38%, 46% and 49% of the MNI counts respectively.

The lower part of the section, **insect zone 1** (155-125 cm., samples 29-24), is rich in insect material, with a total of 451 MNI recovered, across a minimum of 144 taxa. The material from this faunal zone originated from the same stratigraphic unit, comprising well-humified dark peat. This zone is characterised by a good representation of faunal elements associated with coniferous as well as deciduous woodland, but few elements associated with grassland and heath. There are species associated with minerotrophic fen, but virtually none which reflect acid conditions.

Insect zone 2 (125-95 cm, samples 23,22,20,18) contains the richest assemblage of the sequence with 941 MNI, across a minimum of 162 taxa and belongs to the same stratigraphic unit of well humified, brushwood peat. This zone is characterised by an assemblage dominated by a mixture of mesotrophic and ombrotrophic elements. Heath appears to have become a more important. The assemblage appears to reflect a period of flooding or rising groundwater-levels.

Insect zone 3 contains a more restricted faunal assemblage and has been divided into an upper and lower sub-zone (a and b). **Zone 3a** (95-65 cm, samples 16, 14 and 12) contained 215 MNI, across 46 taxa, with **zone 3b** (65-15 cm., samples 10, 7, 4 and 1) containing 207 MNI, across 43 taxa. The stratigraphy represented by these samples is, broadly speaking, dark brown partially humified *Sphagnum* peat, grading into golden brown, unhumified peat with *Eriophorum* and *Calluna* remains. This zone is characterised by an assemblage dominated by many raised mire specialists, although some mesotrophic species persist. *Calluna* heath was important.

6.3.4 Environmental reconstruction

6.3.4.1 Fossil insect zone 1, (samples 29-24) c. 1520-1390 cal BC to c. 1300 BC

The base of the peat at HAT 4 is dated to 1520-1390 cal BC (3165 ± 40 BP, SRR-6127), just over 1,000 years later than other peat initiation dates on Hatfield Moors. This fossil insect zone is characterised by a diverse range of families, including Hydraenidae, Hydrophilidae, Staphylinidae, Scolytidae and Curculionidae.

6.3.4.1.1 The basal sample

It is worth discussing in some detail the contents of the basal sample (29), as this provides some indication of the environmental conditions under which peat initiation began. There appear to have been a number of species indicative of coniferous woodland, such as *Dromius augustus*, which is found in dead branches of *Pinus* (Champion, 1909), as well as the RDB1 species *Ostoma ferruginea*, today restricted to the ancient relict Caledonian *Pinus* forests (Shirt, 1987). This beetle particularly likes rotten *Pinus sylvestris* attacked by the fungus *Polyporus schweinitzi* (Skidmore, *unpubl.*). *Endomychus coccineus* is also associated with *Polyporus* species and is found under fungoid deciduous bark (Palm, 1959). *Dropephylla grandiloqua* is often under the bark of dead trees, either coniferous or deciduous, in old forest areas (Alexander 1994).

There are a number of different taxa of the wood-boring family Scolytidae. The Scolytids attack weakened or recently dead trees, but they are not associated with the later stages of decay (*cf.* Wallace, 1953; Elton, 1966). *Xyleborus saxeseni* appears to prefer deciduous trees (*Quercus* and *Fagus* particularly), but can also live in coniferous trees (Palm, 1959). The presence of either *Fagus* or *Quercus* in the vicinity is indicated by the scolytid *Ernoporus fagi* (Hyman, 1992; Bullock, 1993). *Quercus* is indicated by its leaf-mining weevil, *Rhynchaenus quercus* (Bullock, 1993). *Fraxinus excelsior* also appears to have been growing in the vicinity, the host of the bark beetles *Leperisinus varius* and *Hylesinus oleiperda* (Lekander *et al.* 1977). The deciduous and conifer litter beneath these trees would have created ideal habitats for *Othius punctulatus* (Koch, 1989) and *Anotylus rugosus*. *Alnus* carr is also represented, with the presence of the obligate *Alnus glutinosa* feeder, *Chrysomela aenea* (Lane, 1992).

Amongst the aquatic species recovered are predacious water diving beetles, mainly represented by the larger taxa, (e.g. *Agabus/Ilybius* species), which suggest sizeable pools of water, with some areas of open water. *Agabus bipustulatus* appear to favour deeper pools (> 30 cm deep) (Foster, 1995). All the Dytiscidae recovered are generalist species, indicating the lack of truly acid conditions during this initial phase.

There is an abundance of Scirtidae and Hydraenidae and Hydrophilidae, which are typical of small detritus pools (*Hydrobius piceus*, *Anacaena globosus*, *A. limbata*), abundant with leaves and amphibious plants. Species typical of fen habitats and which are presently rare are abundant, and would have lived on the margins of detritus pools. *Cercyon convexiusculus* is found in fen litter (Hyman, 1992; Friday, 1988). The tiny RDB 3 hydraenid *Limnebius aluta* is a relict fen species (Foster, 1990), which lives in stagnant freshwater (Hansen, 1987). *Hydrochus elongatus* is typical of rich mesotrophic lowland ponds (Merritt, 1995). *Hydraena testacea* is found in small grassy and muddy, somewhat mesotrophic, shaded ponds, rich in *Lemna* spp. (Hansen, 1987), a plant which requires open water. *Ochthebius minimus* is found in stagnant water and ponds, usually in mud, together with the NA species *Hydrochus nitidicollis* (Friday, 1988).

Hydraena britteni/riparia is present in some numbers; unfortunately, it was not possible to identify these specimens to either species. However, in all other samples *H. britteni* is present, so it seems probable that the specimens belonged to *H. britteni* rather than *H. riparia*. *H. britteni* is found in fens (Friday, 1988). *H. riparia* is usually considered a running water species, although it can also be found in stagnant water (Balfour-Browne, 1958). No other species are present indicative of running water, so it is likely these fossils indicate stagnant water.

Reeds and aquatic grasses fringing the water margins would have supported species such as *Phalacrus caricis*, which is found on flowering *Carex* species with smut fungus (Horion, 1960) and *Donacia impressa*, associated with *Scirpus lacustris* and *Carex* spp. (Hyman, 1992). *Trissemus impressa* and *Reichenbachia juncorum* live as predators of mites in marshes, on leaves, moss and on marsh plants (Koch, 1989). *Lesteva heeri* is usually found in debris of *Carex* and *Phragmites* (Koch, 1989).

To summarise, this basal sample indicates an assemblage heavily dominated by minerotrophic fen species, typical of small detritus pools. There were some areas of open water, where the duckweeds, *Lemna* spp. grew. Abundant, wet-loving vegetation grew around the margins and vicinity of these pools. Many of the fossils recovered lived within the rotting plant litter accumulating beneath these plants. *Alnus* carr appears to have been an important habitat within the vicinity. There are faunal indications of drier habitats, however, with the presence of mature, ancient coniferous woodland, or pinewood/heath in the vicinity. Deciduous trees, mixed within the *Pinus*-wood, comprised at least *Quercus*, *Fraxinus* and *Fagus*. There are few indications of *Calluna*-feeding insects, although this does not necessarily imply absence of this habitat.

When raised mire meets the mineral soil in the lagg area of a mire, fen communities occur with *Alnus* carr woodland and *Carex* and *Salix* stands (Heathwaite *et al.*, 1993). It appears that the basal assemblage from HAT 4 is typical of this type of community, reflecting faunal communities from the mire edge and fen community, which probably graded into a mixed deciduous and coniferous woodland growing along its margins.

6.3.4.1.2 The woodland community

Turning to the remaining samples within the insect assemblage zone, there continue to be a number of species characteristic of woodland habitats. These include those living on coniferous and deciduous woodland, although there is an increase in species particularly associated with dead and moribund wood. The rare pinicolous *Ostoma ferruginea* suggests the continued presence of *Pinus sylvestris*, as does *Aplocnemus impressus*, which in Britain tends to be associated with old *Pinus* forest (Hyman, 1992), although in central Europe it is also found on deciduous trees (Horion, 1953; Palm, 1959). The pinicolous Scolytid *Tomicus piniperda* often damages trees which are stressed by drought or defoliation by the *Pinus* looper moth *Bucephalus pinaria*

(Winter, 1993). This could suggest that the *Pinus* forest was becoming increasingly stressed. This species appears in sample 25, at a time when other wet-loving and aquatic species begin to increase, suggesting that the most obvious source of stress would have been the rising water-table. However, as Nilssen (1993) points out, this species is common in all *Pinus* forests. It is interesting that *Hylesinus crenatus* is recovered within the same sample; this species is especially common under thick bark of old *Fraxinus,* attacking only dying trees and it often repeatedly attacks damaged trees (Palm, 1959).

Besides *Pinus* and *Fraxinus*, other trees continued growing in the vicinity. The non-British *Rhyncolus punctatulus* appears in sample 28, an *Urwaldtier* species, which feeds upon deciduous and coniferous stumps (Reitter, 1916). *Cerylon ferrugineum* is usually associated with *Quercus* and *Fagus* (Donisthorpe, 1939). The notable B species *Synchita humeralis,* is characteristic of old forests (Dajoz, 1977) and is found on fungoid bark and wood of freshly dry deciduous trees, particularly *Alnus* (Palm, 1959), as well as underneath *Fagus* (Donisthorpe, 1939) *Betula* (Skidmore, 1972) and *Quercus* bark (Koch, 1989). *Rhamphus pulicarius* and *Athous haemorrhoidalis* suggest the presence of trees/shrubs such as *Salix*, *Populus, Myrica* and *Betula* (Reitter, 1911; Morris, 1993). The abundance of rotting fungoid wood and fungi in the woodland would have created ample *pabula* for species of the genera *Abdera* and *Agathidium*; *Sepedophilus immaculatus* is often found in leaf litter (Johnson, 1991). A range of plant litter, mouldy bark as well as fungi would have created a rich diversity of habitats for many beetles on the woodland floor.

The Carabidae *Agonum fuliginosum, Pterostichus nigrita, P. minor* and *P. diligens* are all hygrophilous species which are common in fen woodland and peat bogs (Lindroth, 1945). *P. diligens* first appears during this assemblage zone, but thereafter becomes an important faunal component, especially as the bog becomes more ombrotrophic, suggesting it has a preference for more acid substrates. The notable B species *Elaphrus uliginosus* often prefers rich fens with *Carex, Eriophorum* and mosses (Lindroth, 1985). There are no species characteristic of acid bogs.

6.3.4.1.3 The heath communities

Just six individuals are ascribed to the sandy heath/*Calluna* and heath woodlands categories, including the *Calluna* feeder *Micrelus ericae*. *Rhinosimus planirostris* is typical of pinewoods and heaths (Hyman, 1992).

6.3.4.1.4 The aquatic communities

Amongst the aquatic species, there are a number of generalists, which live in a variety of wetlands (*Agabus bipustulatus*, *Hydrobius fuscipes*). There are many species which live in all types of bogs (*Hydroporus* spp., *Hydraena britteni*) as well as those which live in non-acidic bogs. The assemblage is similar to that recovered within the basal sample and includes *Hydraena testacea*, which appears to increase in numbers through the period represented by the zone, perhaps reflecting increasing mesotrophic conditions in the area. *Limnebius aluta, Hydrochus ignicollis, H. carinatus* and *H.elongatus* are all typical of rich mesotrophic lowland ponds and fen drains (Merritt, 1995). *Hydrochus augustatus* is found in leaf- and vegetation-rich standing woodland waters (Koch, 1989). Sample 25 contains the fragments of the RDB 3 Greater Silver Water beetle, *Hydrophilus piceus*, which is found in marshes, in vegetation-rich standing waters, mostly in *Phragmites* detritus (Friday, 1988; Koch, 1989). An almost complete specimen of this beetle was found in 1903 from undated deposits on Hatfield Moors (Bayford, 1903). In contrast, there are no aquatics characteristic of acid bogs.

There may have been some moving water in the vicinity. The notable B species *Ochthebius bicolon* is usually found in freshwater rivers or streams, mainly slower water at grassy edges among vegetation or on banks, occasionally (probably accidentally) it is found in stagnant water (Hansen, 1987). *Hypnoidus riparius* is present in several samples and can sometimes be associated with moving water and flood debris, as well as being found on stream and river banks, in moss and litter (Koch, 1989). *Limnebius truncatellus* is usually associated with running water (Friday, 1988) and its occurrence in sample 24 could indicate some moving water.

The abundance of Scirtidae, Hydraenidae and Hydrophilidae (*Hydrobius piceus, Anacaena globosus, A. limbata*) are typical of small detritus pools, abundant with leaves and amphibious plants. The water beetle *Ilybius subaeneus* prefers richly vegetated pools with areas of open water and a soft muddy substrate (Merritt, 1995). *Cyphon padi* lives in reed swamp at edge of ponds (Richards, 1926). The presence of *Carex* is suggested by the phalacrid *Phalacrus caricis* (Bullock, 1993). Hygrophilous species are relatively abundant and include those that live in plant detritus in wet situations (e.g. *Cyphon* spp., *Megasternum obscurum, Stenus comma* and *Lathrobium* spp.).

6.3.4.1.5 The decay community

There is a small fauna associated with animal and plant debris. *Aphodius contaminatus* and *A. sphacelatus* are found in dung of various animals as well as in decaying plant litter (Jessop, 1986). There are other members of the dung beetle genus *Aphodius* and these perhaps reflect the presence of herbivores roaming the area.

6.3.4.2 Fossil insect zone 2, (samples 23-18), c. *1320-1030 cal B.C. to 1000 cal BC*

This zone is characterised by a diverse range of families, including Carabidae, Dytiscidae, Hydraenidae, Hydrophilidae, Staphylinidae, Elateridae, Scirtidae, Cerambycidae, Chrysomelidae, Scolytidae and Curculionidae.

Several different factors characterise this insect assemblage zone. There is an increase in woodland taxa, mainly dead-wood species, as well as an increase in species associated with damp woodlands. There are also small increases in the heath-indicator species and those indicative of grassland and herbs. There are larger numbers of insects of non-acid conditions, as well as those indicative of acid conditions. Aquatic habitats are abundant.

6.3.4.2.1 The woodland community

There is a very abrupt decline of saproxylic species at the close of this zone, represented by sample 18. However, throughout this zone there is a varied wood-loving population. Species associated with *Pinus* habitats are still represented, (e.g. *Tomicus piniperda*) although these are outnumbered by those associated with dead wood, most of which are considered *Urwaldtier*, including *Ostoma ferrugineum* and *Aplocnemus impressus*. The saproxylic fauna suggests that there was still some *Pinus* growing in the vicinity, but that there was also a high proportion of old, dead, rotting and fungoid *Pinus* on the margins of the developing mire.

There were other deciduous trees present. Members of the genus *Rhynchaenus* live on a variety of broad-leaved trees, such as *R. fagi* on *Fagus sylvatica* (Bullock, 1993). *Rhynchaenus rusci* is found on *Betula*, together with *Rhamphus pulicarius*, which can also be found on *Salix*, *Populus*, *Myrica* (Richards, 1926; Morris, 1993). *Dromius agilis* and *D. meridionalis* live under loose bark of various coniferous and deciduous standing trees (Palm, 1959; Alexander, 1994).

Taxa associated with dead deciduous wood were particularly important, including a number of *Urwaldtier* species, some of which are non-British. *Tenebrioides fuscus* is a beetle especially found in primary woodland areas, under deciduous tree bark (especially *Quercus*) on fungoid trunks and branches (Vogt, 1967). This is a non-British species and this is represents the first record for this species in Britain. Other rare old forest species recovered were *Melasis buprestoides*, which lives in moribund or dead wood, particularly of *Quercus* and *Betula* (Skidmore, *unpubl.*), but also under *Fagus* (Donisthorpe, 1939). *Dorcatoma chrysomelina* is found in red rotted wood of deciduous trees, particularly of old *Quercus* attacked by fungal mycelia of bracket fungi (Garland, 1983; Koch, 1989; Nash, 1975). There are also records from red rotted *Fraxinus* (Alexander, 1994). The cerambycid *Leiopus nebulosus* is largely restricted to old woodlands; its larvae bore beneath the bark of dead *Quercus* branches, often on living trees (Crowson, 1962; Garland, 1983). *Dryocoetinus villosus* is found under thick *Quercus* bark, especially on large stumps and older trees damaged by fire, occasionally also in thick *Fagus* bark (Garland, 1983; Palm, 1959). Species such as *Grynobius planus, Anaspis* spp. and *Abdera* spp. would have found ample *pabula* amongst all the moribund and rotting wood. Trees would have been covered with fungi, creating suitable habitats for *Stephostethus augusticollis* and the RDB Notable B species *Orchesia micans*.

The Notable B species *Scolytus ratzeburgi*, the birch bark beetle, attacks damaged trees, often those damaged by flooding, fire or defoliation by other insects (Palm, 1951; Palm, 1959). It may have been attracted to the area because of an abundance of stressed trees subjected to a rising water table. Evidence for trees coming under increased stress is also suggested by the *Alnus* bark beetle *Dryocoetinus alni,* which, in particular, attacks standing trees which are beginning to dry out or which are weakened by fire, a high water table or sickness (Palm, 1951; Koch, 1989). *Denticollis linearis* tends to feed upon larvae of such Scolytidae, living in rotting stems of old deciduous trees particularly *Alnus* in a damp, shady site (Reitter, 1911; Palm, 1951; Alexander, 1994). Within lighter areas of this woodland and woodland margins there were species such as *Grammoptera ruficornis* and *Xylocleptes bispinus*, the former of which is found on trees and shrubs, such as hawthorn (Palm, 1959), the latter on stems of *Clematis vitalba* (Bullock, 1993).

Alnus carr woodland continued to be an important component, as the *Alnus* feeder, *Chrysomela aenea* and *Abdera flexuos* suggest. This mesophilous forest litter would have been suitable for the scydmaenid *Stenichnus collaris* and the scirtid *Microcara testacea.*

6.3.4.2.2 The heath and grassland community

This community is far more important during this period compared with insect zone 1. Ground beetles which are usually found on heaths, with sandy substrates, such as *Bradycellus ruficollis* and *Amara similata*, are present in this period. Others include the notable B species *Ceutorhynchus geographicus*, which has a preference for sandy areas and sun exposed dry places (Koch, 1992) and is associated with Viper's-bugloss *Echium vulgare* (Bullock, 1993). The *Calluna* feeding chrysomelid *Lochmaea suturalis* as well as the *Calluna* ladybird *Chilocorus bipustulatus* also occur. There is a small community of species associated with grassland and herbs (e.g. *Chaetocnema concinna*). Members of the genus *Sitona* are usually found in grassland on various species of Fabiaceae; *Derocrepis rufipes* is oligophagous on *Vicia* spp. *Cytisus* spp., *Astragalus* spp., *Lathyrus* spp., *Medicago* spp., (Koch, 1989).

6.3.4.2.3 The non-acidic and acidic communities

Both acid and fen indicator-species are present. *Agonum fuliginosum* is found in minerotrophic to mesotrophic bogs (Koch, 1989). *Pterostichus nigrita, P. minor* and *P. diligens* occur together, as they do in this assemblage and are often associated with *Alnus glutinosa* swamps and peat bogs (Lindroth, 1945), although *P.diligens* appears somewhat more tolerant of acid conditions that the other taxa (see section 6.5.5.3 for a fuller discussion). There are also a good range of species which live in plant litter in fens, such as *Cercyon convexiusculus*, and *C. sternalis* (Friday, 1988). This component appears to abruptly disappear at the end of this assemblage zone.

A similar change appears to occur to species living in reeds, sedges and other water-side plants, whose population appears to decline abruptly at the end of the zone. A diverse ranges of species make up this community. Species such as *Donacia marginata* and *D. vulgaris* are present, both associated with emergent vegetation in boggy and marshy shores of pools. The former taxon is associated with *Sparganium erectum* and *Typha* spp. (Stainforth, 1944; Koch, 1992), the latter with *Typha latifolia* and *Schoenoplectus lacustris*; it has also been recorded from *Carex* spp. and *Glyceria maxima* (Stainforth, 1944). *Plateumaris sericea* is a species which pupates in rhizomes and roots of *Typha latifolia, Iris pseudacorus, Schoenoplectus lacustris, Bolboschoenus maritimus* and *Sparganium erectum* (Stainforth, 1944), on *Carex* and yellow water-lilies *Nuphar* spp. (Bullock, 1993) and on the white water-lily *Nymphaea alba* (Lane, 1992). The species *Limnobaris dolorosa* is usually found on Juncaceae and Cyperaceae, *Carex* spp., *Scirpus* spp. and *Cladium mariscum* (Koch, 1992). *Carex* certainly grew in the vicinity, as indicated by its associate beetle, *Phalacrus caricis*. The beetle *Prasocuris phellandri* is oligophagous on pond-side aquatic Umbelliferae, such as the water-dropworts *Oenanthe phellandrium*, cowbane *Cicuta virosa* and greater water-parsnip *Sium latifolium*; its larval food is marsh marigold *Caltha palustris* (Harde, 1984; Koch, 1992). *Galerucella calamariensis* is monophagous on purple-loosestrife, *Lythrum* *salicaria*, another species associated with water side vegetation in marshes and fens (Bullock, 1993; Koch, 1989). *Altica lythri* is oligophagous on wet loving plants such as *Epilobium hirsutum* and *Chamaenerion angustifolium* (Phillips, 1977; Marshall, 1980; Crowson, 1981; Koch, 1989). All species are indicative of minerotrophic/mesotrophic conditions.

In contrast, there are no definite identifications of *Plateumaris discolor,* usually associated with ombrotrophic conditions, although there are some individuals which could only be identified to *P. discolor/sericea*. *Altica britteni* is usually found on *Calluna*, *Erica* and *Empetrum* (Marshall, 1980). The staphylinid *Acidota crenata* is often found in *Sphagnum* and *Carex* bogs, although it can also be found in quite dry habitats in *Pinus* forests (Campbell, 1982). The faunal evidence conveys the impression of partly overgrown pools with emergent vegetation, including a rich variety of aquatic plant species, with a distinct *Sphagnum* and leaf litter layer.

6.3.4.2.4 The aquatic communities

There is a large increase in aquatic species, particularly those associated with vegetation- rich communities. This category is largely represented by members of the Scirtidae family, which in samples 20 and 18 represent almost 50% of the MNI recovered.

There is a restricted community of aquatic generalists, which after the end of this zone abruptly disappear. This is represented by the larger Dytiscidae, such as members of the genus *Ilybius* and *Agabus*. Members of the genus *Graphoderus* tend to be associated with stagnant water in deep pools or small lakes. Evidence from all these species suggests the presence of deeper pools. There are a significant number of individuals of the genus *Hydroporus* as well as *H. scalesianus,* which is considered a fen species in Britain (Friday, 1988). However, this beetle appears to be acid tolerant, when its European habitat is examined, since it is found in bog pools, in wet *Sphagnum* and in floating vegetation mats (e.g. Koch, 1989). It is probable that other factors are as important to this species as water acidity (e.g. pond substrate, the amount of silt in the water, the quality and quantity of *Sphagnum* mats, the presence of population limiting factors, such as predators). Pools with detritus would have been a favourable habitat to the hydrophilids *Hydrobius fuscipes* and *Anacaena globosus* (Hansen, 1987).

Amongst the non-acidic taxa are species such as *Enochrus coarctatus*, *Hydraena testacea,* which prefers *Lemna* covered standing waters (Lohse, 1971) *H. britteni* and *Limnebius aluta,* all of which are indicative of mesotrophic conditions (Friday, 1988).

The Notable B species *Graptodytes granularis* is found in shallow ponds with dense marginal vegetation and on open, seasonally flooded parts of fens (Nilsson and Holmen, 1995). The RDB 3 hydrophilid *Hydrochus brevis* is found in bog and woodland pools, in *Sphagnum* and *Phragmites* litter (Koch, 1989).

There are also a range of aquatic acidic-loving species. *Hydroporus melanarius* appears in sample 18, a species which is found in *Sphagnum* (Friday, 1988). *H. tristis* is found in acid waters, particularly in bog pools (Lee, 1981; Nilsson and Holmen, 1995). A similar habitat is required by *Agabus affinis* and *Hygrotus decoratus*. The presence of these beetles is probably indicative of increasingly acid conditions.

The evidence suggests that the assemblage of insect zone 2 represent an intermediate or mesotrophic faunal community. Sample 18 shows an obvious increase in acid loving species, as well as a general increase in aquatic species such as *Hydroporus* spp., suggesting increasingly wet and ombrotrophic conditions. Increases in the larger Dytiscidae indicate larger pools, possibly created by rising water levels or due to seasonal flooding. *Gyrinus aeratus* is found in this sample, a species which is found especially in slow flowing small rivers, although it can also be found in ponds and bog pools (Koch, 1989). The presence of some moving water may be indicated by small numbers of *Limnebius truncatellus* and *Ochthebius bicolon*, both of which are associated with running water (Friday, 1988).

6.3.4.2.5 The hygrophilous communities

The littoral pool zone, with its rich plant community, would have been attractive to many hygrophilous taxa, such as the scirtid *Cyphon padi*, which was recovered in considerable numbers from these samples. This species is usually found in reed swamp at the edge of ponds, for instance in *Caltha palustris* (Richards, 1926; Sinclair, 1997), a plant species almost certainly present. Other beetles living in this damp zone as well as other damp places (e.g. under leaf litter) would have members of the genus *Stenus* and *Lathrobium*, such as *L. fulvipenne*, *L. brunnipes*, *L. longulum* as well as the hydrophilid *Megasternum obscurum*.

6.3.4.2.6 The decay community

Members of this community overlap with many of the preceding categories, particularly the wood-feeding and plant-litter taxa. This category tends to include those species that live in both animal and plant debris. Several members of the genus *Aphodius* are represented, including *Aphodius ater*, which is a eurytopic species found in droppings of various animals, as well as in compost and decaying vegetation (Landin, 1961). *Anotylus rugosus* is found in a variety of rotting materials, including plant and animal debris (Koch, 1989). The notable B species *Platydracus fulvipes* is found in wet woodland in fens as well as in moss, at roots of plants, under stones, in grass tussocks, and in dung (Hyman, 1994). There is no reason to believe that any of these elements would have been anything more than the background fauna associated with the fen woodland.

6.3.4.3 Fossil insect zone 3, c. 1,000 cal BC to c. 700 AD

This insect zone is characterised by some very abrupt faunal changes, highlighting the transition from mesotrophic to ombrotrophic conditions. There are subtle differences between the lower (3a) and upper (3b) part of this zone, mainly in differing mesotrophic and ombrotrophic species.

The zone is characterised by a range of families including Carabidae, Dytiscidae, Staphylinidae, Scirtidae, Chrysomelidae, Curculionidae; members of the Hydraenidae, Hydrophilidae and Scolytidae, previously plentiful, are notably absent. The samples contained much lower numbers of individuals and species. The peat ranged from fairly well humified brushwood peat (see Appendix C), through to unhumified *Sphagnum* peat. The latter type of peat is likely to have accumulated rapidly, although this may not have been the case for the more humified brushwood peat. A lower number of fossils is likely be incorporated within deposits which accumulate rapidly, compared with deposits which have taken longer to accumulate, such as the brushwood peat. The low numbers of individuals recovered from both deposits, therefore, are likely to be a product not only of the higher rates of deposition, but also of the more limited and restricted fauna, reflecting some substantial changes on the mire.

6.3.4.4 Fossil insect zone 3a (samples 16-12)

The lower part of the zone is characterised by a continued presence of heath/*Calluna* communities, a steady decline in fen communities, and a sharp increase in acid peatlands taxa. There is also a decline in hygrophilous taxa and a marked decline in aquatics, particularly amongst the generalists, fen species and those associated with well-vegetated water. In contrast, the aquatic acid-loving taxa remain high.

6.3.4.4.1 Woodland communities

There were virtually no species associated with woodland and trees, except the *Alnus* feeder *Chrysomela aenea*, which persists in samples 16 and 14, indicating that *Alnus* continued growing in the area for a period.

6.3.4.4.2 Heath and grassland communities

Several species are indicative of heath. The ground beetle *Bradycellus ruficollis*, a stenotopic species of *Callunetum*, (Lindroth, 1945), the heather ladybird *Chilochorus bipustulatus* and the heather weevil *Micrelus ericae* all strongly support the importance of this habitat. The presence of several insects associated with *Betula* (e.g. *Rhynchaenus rusci* and *Rhamphus pulicarius*) indicates heath with *Betula*.

6.3.4.4.3 Peatland communities

This component is mainly composed of acid-loving/tolerant taxa. *Pterostichus diligens* continues to be present, whereas all its congeners disappear (*P. nigrita*, *P. minor*), confirming the idea (section 6.5.5.3) that this species appears to be more acid tolerant than some of its habitat information would suggest (e.g. Lindroth, 1974; Koch, 1989). There are no species associated with fens and plant debris, but there are several individuals of *Plateumaris sericea*, (sample 16) a species which lives on aquatic plants (*Typha latifolia*, *Iris pseudacorus*, *Schoenoplectus lacustris*, *Bolboschoenus maritimus* and *Sparganium erectum* [Stainforth, 1944], *Carex* and *Nuphar* species [Bullock, 1993]), in mildly basic environmental conditions. Within the same sample *Altica lythri* is present, which is oligophagous on wet-loving plants, such as *Epilobium hirsutum* and *Chamaenerion angustifolium*, and more rarely on *Lythrum* spp. (Phillips, 1977; Marshall, 1980; Crowson, 1981; Koch, 1989). The presence of these beetles suggests mesotrophic conditions. However, for the rest of the sequence, *P. discolor*, typical of acid raised bogs and associated with *Sphagnum* and *Eriophorum*, is important, suggesting the transition to ombrotrophic conditions. *Altica britteni* also appears, found on *Calluna*, *Erica* and *Empetrum* (Marshall, 1980). The transition to fully ombrotrophic conditions appears to have occurred sometime between samples 16 and 14 (95 to 75 cm).

6.3.4.4.4 Aquatic communities

Amongst the aquatic species, there is a very clear decline in generalist species and those which live in all types of bogs, except in the dytiscid *Hydroporus scalesianus* which appears to thrive at this point. The significance of this species has already been discussed (section 6.3.5.2.4) and appears to react positively with acidic conditions. There are no fen species, except a possible *Ilybius quadriguttatus*, which Whitehead

(1992a) suggests is largely a fen species, although Nilsson and Holmen (1995) record it from densely vegetated, permanent water bodies. There is a good range of acid aquatic species, however, such as *Hydroporus obscurus*, *H. melanarius*, *H. tristis*, as well as *Enochrus affinis*. There are few species indicative of detritus and plant litter. The ubiquitous members of the genus *Cyphon* decline compared with previous samples. Many of the hygrophilous taxa also decline, although many of the Staphylinidae are still present (e.g. members of the genus *Lathrobium*).

6.3.4.5 Fossil insect zone 3b (samples 10-1)

Several subtle changes seem to have occurred during the upper part of the sequence. Ombrotrophic conditions are still evident, but there appear to have been some small changes in the heath faunas and a small increase in mesotrophic species. Amongst the aquatics, those associated with acid conditions are still evident, but there appears a general decline in the aquatics throughout zone 3, a situation mirrored by the lack of large water beetles requiring large areas of open water. The presence of *Hylastes opacus* and *Cymindis vaporariorum* (although the latter species is mainly associated with peatlands as well as pinewood heaths) at the top of the profile may indicate the presence of *Pinus* locally.

6.3.4.5.1 The heath communities

This habitat continues to be important, with the presence of *Micrelus ericae* and *Altica ericeti*, the latter a heathland and raised mire specialist, associated with *Erica tetralix* and *E. cinerea* (Hyman, 1992). The ground beetle *Bradycellus harpalinus* is an exclusively sandy ground species found especially on heaths under *Calluna* (Lindroth, 1945, 1986).

6.3.4.5.2 The peatland communities

There appear to have been some subtle changes in the composition of the Carabid fauna towards the top of the profile, with the presence of *Pterostichus diligens*, but also *P. nigrita* and *Agonum fuliginosum*, both of which are found in mesotrophic bogs (Koch, 1989). The latter is also absent in very wet bogs and probably reflects the less wet nature of the bog at this time, which is also evident amongst the aquatic species. Present is also the raised mire specialist *Agonum ericeti*, which is stenotopic on ombrotrophic sites or wet heath (Holmes *et al.*, 1993). Both *Altica britteni* and *Plateumaris discolor* continue to be important elements within these samples.

6.3.4.5.3 The aquatic community

The aquatic community reflects many of the elements that had been present in zone 3a, except that there are a few elements associated with mesotrophic conditions, as well as ombrotrophic conditions. This is evident from the presence of species such as *Hydraena britteni, Hydroporus umbrosus* and *Limnebius aluta.* However, acid-loving species continue to be evident, such as *Hydroporus obscurus*, *H. melanarius*, *H. tristis* and *Enochrus affinis.*

6.3.5 Diversity indices

Figure 6.3 shows the diversity values for HAT 4. Diversity clearly declines through the samples. The values reflect extremely well the faunal changes seen at this location and the different assemblage zones show distinct diversity values. The lower samples range between 70-50 Fisher's α, with the two lowest samples showing the highest diversity of species. Species richness is generally far greater in minerotrophic fens (Roper, 1996), a factor which the values appear to reflect. The higher values for the two basal samples is probably related to the presence of ancient woodland in the vicinity. The mesotrophic samples represented by assemblage zone 2 show diversity ranging between 50-40 Fishers α. The ombrotrophic samples (zone 3) show a dramatic decline (18-10 Fishers α), as the raised mire specialists take over, although the values are not as low as those values which Roper (1996) reported for ombrotrophic samples at Thorne Moors. Here, her lowest values were in the region of 3.5.

6.3.6 Environmental interpretation

Assemblage zone 1 is characteristic of minerotrophic fen conditions. Mature coniferous and damp deciduous woodland grew in the vicinity, comprising *Pinus* as the most important tree, as well as *Quercus, Fagus, Fraxinus* and *Alnus*. The fauna associated with this woodland indicates a forest with many late successional habitats and an abundance of dead wood. Many of the species are today associated with primeval, undisturbed woodland. There are also indications of heath, as well as species that are typically found in a fen community. It seems likely that this assemblage represents a habitat on the margins of the developing mire, a lagg fen community.

Fossil insect assemblage zone 2 comprises a number of different environmental elements, characterised by a mixture of acid and non-acid indicators, suggesting this period represents a transitional stage (mesotrophic) in raised mire development. *Pinus* appears to have continued growing, although the higher numbers of species associated with dead and rotting wood suggests that there was more dead than living wood in the area. Other deciduous trees seem to have been present, (*Fagus*, *Betula*, and *Alnus*, possibly *Quercus*) although again, mainly rotting wood taxa represent these habitats. Heath species are important during this phase. A sharp rise in aquatics suggests a period of increased wetness in this area, possibly due to flooding or run-off from the mire.

In contrast, fossil insect zone 3a contains few species indicative of mesotrophic conditions, with a large proportion of ombrotrophic-indicating species, including some raised mire specialists. Heath was also an important habitat. Zone 3b contains many of the elements seen during the early part of the zone, but also indicate some return to more mesotrophic conditions, or possibly to drier conditions. The impression from this zone is of fluctuating conditions, with many heath as well as ombrotrophic-indicating taxa.

6.4 Lindholme A, Hatfield Moors (LIND A)

6.4.1 Introduction

Three fossil insect assemblages were analysed from the Lindholme A site, comprising 225 MNI, belonging to *c.* 91 different taxa, covering 19 families. The site chosen is on the present margins of the Moors, from a very desiccated peat face, and highlights the potential of sampling even dry deposits. The stratigraphic relationships between samples are shown in Figure 4.8. Table 6.4 tabulates the list of fossil Coleoptera.

6.4.2 Age of the deposits

No radiocarbon dates were obtained for this sequence. The nearest available dates come from the Lindholme B sequence, about 600 metres away (see Table 6.1 for dates). The base of the peat consists of partially humified peat with *Betula* macrofossils. This is rather different from the black, amorphous peat seen in many other basal deposits on Hatfield Moors, including those at Lindholme B. Dates so far would suggest that the black amorphous peat characterises the oldest peat deposits on the Moors, including those from Smith's (1985; *in press*) palynological sequences, HAT 1 and HAT 2. On stratigraphic grounds, it could be argued that the LIND A basal deposit is later than the black amorphous peat. At LIND B, this is dated to >2700-2350 cal BC (3990 ± 60 B.P., Beta-91800) (60 cm. from the base) and at HAT 3 to 3350-3030 cal BC (4480 ± 45 B.P., SRR-6119), with dates of 2820-2660 cal BC (4180 ± 70 B.P., CAR-168) and 3040-2890 cal BC (4335 ± 75 B.P., CAR- 254) for Smith's (1985) HAT 1 and HAT 2 sites respectively. In addition, samples 7 and 6 from LIND A contained charred wood and charred *Calluna* seeds, respectively. Smith (*ibid.*) also noted charred *Calluna* at his sites, above the basal deposits, which he dates to 2040-1870 cal BC (3570 ± 70 BP) at HAT 1 and 2200-1970 cal BC (3685 ± 65 BP), 4 cm. below the charcoal horizon at

HAT 2. If the charred material noted at LIND A relates to the same episode, the base of the sequence would date roughly to *c.* 2,000 BC.

6.4.3 Results

The samples from LIND A contained a range of reasonably well-preserved insects, although the samples score rather less highly on the Preservation Index (2, 3 and 4, for samples 7, 6 and 3 respectively). Members of the families Carabidae, Dytiscidae, Hydrophilidae, Staphylinidae, Curculionidae and Scolytidae dominate the faunal assemblages. Members of the genus *Hydroporus* are reasonably abundant, representing about 30%, 17% and 16% of samples 7, 6 and 3 respectively, but did not dominate the assemblage. This is the only site where members of the family Scirtidae, a family which is usually abundant on sites from both Moors, and which inhabits damp plant litter and moss in the vicinity of pools, are poorly represented. The elytra of these insects are particularly fragile, and whilst this could explain their absence in the bottom-most sample, with its lower preservation levels, it does not explain their absence in the other samples. The insect habitat categories represented by the assemblage are shown in Figure 6.4. Figure 6.5 shows the diversity values for this assemblage.

6.4.4 Environmental reconstruction

6.4.4.1 The woodland community

Whilst saproxylic taxa represent an important element within samples 7 and 6, this is not the case in sample 3. The lower samples contain an important *Pinus*-loving element with species such as *Rhyncolus ater*, *Pityophthorus lichtensteini* and the non-British *Cryptolestes corticinus*, most of which are found in rotting wood, underneath bark (Reitter, 1911; Palm, 1951). The scolytids *Hylastes opacus* and *Tomicus piniperda* are also found in pinewood on heaths and dunes (Koch, 1992). In contrast, the upper sample contains no pinicolous elements.

The lower samples also contain taxa indicative of deciduous woodland. *Cerylon ferrugineum* is a predator on various bark beetles and is found under loose rotting bark of many deciduous trees in wood mould, in old tree fungi and wood fungi (Koch, 1989). It is particularly associated with *Fagus*, but also occurs in *Quercus*, *Ulmus*, *Tilia* and *Betula* (Reitter, 1911), almost exclusively in areas of primary woodland (Garland, 1983). Another member of the genus, *C. histeroides* is also present. It is found in similar habitats, under decayed bark of both deciduous and coniferous trees (Horion, 1962). *Pediacus dermestoides* is found beneath the bark of deciduous trees, particularly *Fraxinus* and *Quercus* in the early stages of decay (Whitehead, 1996), and is widespread in ancient woodlands and pasture woodlands (Alexander 1994). *Rhynchites* spp. are found associated with broad-leaved trees and shrubs, such as *Quercus*, *Betula* and *Salix*. There are indications of areas of swampy woodland, such as *Alnus* carr. *Agonum obscurum* is found especially in deciduous and mixed forests, living in damp, shaded places among litter and moss, and is particularly common in stands of *Alnus* and *Fraxinus* in forest swamps (Lindroth, 1986).

During the earlier period represented by samples 7 and 6, besides *Pinus*-woodland, deciduous woodland was growing in the vicinity. However, by the time the peat representing sample 3 was deposited, only *Betula* is indicated by the insect record, the host of *Scolytus ratzeburgi*.

6.4.4.2 Heath and grassland communities

An important heathland element is represented by sample 3. Previous samples contained a small number of taxa associated with heathland. Sample 3 contains several heath taxa, such as *Bradycellus ruficollis*, which is often found on *Calluna* heath (Delany, 1960). *Lochmaea suturalis* is a phytophagous species found exclusively on *Calluna vulgaris* (Bullock, 1993). There are also a number of grass/herb taxa, such as *Chaetocnema concinna*, which is associated with *Polygonum* and *Rumex* species (Bullock, 1993), although it can also be found in moss in willow swamp (Donisthorpe, 1939). *C. hortensis* is found on *Plantago* species or on Poaceae (Lane, 1992). Both species are likely to have been living on the heath or dry woodland margins, and may represent early successional habitats created in the vicinity by natural disturbances (e.g. windblow of trees).

6.4.4.3 The acid and non-acid communities

There are some indications that the lower samples are less acid than the upper sample, with species such as *Pterostichus minor*. *P. diligens* is also present, a species characteristic of wetland sites with peaty substrates, along with *P nigrita* (Eyre and Luff, 1990). The upper sample contains *Plateumaris discolor*, typical of acid raised bogs (Koch 1992); the reed beetles recovered in the lower samples could only be identified to *P. sericea/discolor*. Sample 3 also contains *Altica britteni*, whose larvae feed on *Calluna*, *Erica* and *Empetrum* (Marshall, 1980).

6.4.4.4 Aquatic communities

Differences between the lower and the upper samples are also evident amongst the aquatics. Generalist aquatic species, such as *Agabus bipustulatus* and *Colymbetes* *fuscus*, show a marked decline through the sequence. *Agabus unguicularis*, in the basal sample, is a species found mainly among dense vegetation in fens (Nilsson and Holmen, 1995), and is often associated with mesotrophic fen (Merritt, 1995). *Ilybius aenescens* is found in acid water, over deeply flooded *Sphagnum* (Friday, 1988), although Nilsson and Holmen (1995) suggest it is eurytopic and is found in most types of water bodies, often in bog pools. The evidence from the lower samples could indicate a mixture of acid and less acid tolerant taxa. However, sample 3 very clearly contains more acid tolerant taxa, such as the Notable B species *Paracymus scutellaris* and *Enochrus affinis*, both of which are found in shallow acid waters, in bog pools (Friday, 1988; Hyman, 1992).

A high number of members of the genus *Hydroporus* are present, particularly in the two basal samples, including small numbers of *H. scalesianus*. This beetle is usually found in fen and carr, sometimes in peat bogs (Shirt, 1987). Shallow pools (< 5 cm) are frequently dominated by small beetle species of the genus *Hydroporus* (Foster, 1995), although the presence of both *Agabus bipustulatus* and *Ilybius aenescens*, which favour deeper pools (Foster, 1995), would suggest habitats suitable for other Dytiscidae. In contrast, the upper sample appears to indicate a decline in small water beetles and show a complete absence of any of the large Dytiscidae. This could indicate that aquatic habitats had declined, where previously aquatic habitats appear to have been reasonably large in extent and/or abundant. This may have been in response to a drier episode in the bog's development.

6.4.4.5 The hygrophilous communities

There are more taxa and individuals associated with wet plant debris in the lower two samples, represented by species such as *Stenus* spp., *Lathrobium fulvipenne*, *L. brunnipes* and *L. longulum*, all species which are often associated with swamps, alder carrs, under leaves, moss and grass tussocks, in *Sphagnum* and in detritus of *Phragmites* (Koch, 1989). *Anacaena globosus* is a species typical of detritus pools (Koch, 1989), and is common in the lower samples. *Lesteva punctata* is found in fen woodland, banks of woodland streams, in flooded mosses, under debris, wet leaves and flood debris and in *Carex* (Koch, 1989). *Stenus bimaculatus* and *Trissemus impressa* are found in detritus and rotting vegetation, particularly in bogs (Koch, 1989). In contrast, the upper sample 3, contains just one taxon indicative of wet plant debris.

There is a notable absence of species indicative of emergent vegetation associated with water margins, including members of the reed family *Donacia* and *Plateumaris*, which are represented in very small numbers. There is a lack of members of the families Scirtidae and Hydraenidae and to a lesser extent members of the Hydrophilidae, many of which are typical of small detritus pools, abundant with leaves and amphibious plants. This suggests that this habitat was more limited compared with some of the other palaeoentomological sampling locations (e.g. HAT 4).

6.4.5 Diversity indices

Figure 6.8 shows the diversity of the samples from LIND A. It is interesting that diversity is lower in the basal sample, but that the samples above have a higher diversity. It is not easy to explain this pattern, which might not be significant. It is possible that the increase in heath elements within samples 6 and 3 could explain the higher diversity. The diversity values are within the range experienced for mesotrophic samples (as seen at HAT 4), corroborate the environmental evidence.

6.4.6 Environmental interpretation

The overall impression of the fauna from this location is indicative of a wet, pinewood heath. There were other deciduous trees growing close-by, probably *Quercus*, *Betula*, *Fraxinus*, *Fagus*, possibly *Alnus*. With increasingly ombrotrophic conditions, *Pinus* trees were not able to live on the mire. Open areas of *Calluna* heath continued growing. Drier conditions are reflected in the aquatic species, particularly within the period represented by the upper sample. It is interesting that in this later phase there is an increase of beetles associated with rotting animal and plant debris, possibly indicating the presence of dung, as well as decaying plant litter in the vicinity. *Aphodius contaminatus* is a eurytopic species which likes sandy places and is found in all kinds of dung, very often in horse, as well as cattle manure (Landin, 1961). It is possible that the increase in this element in the upper sample is a reflection of the drier conditions in this location, on a marginal area of the Moor, where herbivores may have been taking advantage of the drier conditions on the mire for grazing.

6.5 Lindholme B, Hatfield Moors (LIND B)

6.5.1 Introduction

Four fossil insect assemblages were analysed from the Lindholme B site, comprising 448 MNI, belonging to *c.* 67 different taxa, covering 14 families. Samples 9, 12, 15 and 18 were selected to provide a broad picture of environmental change on the mire, close to Lindholme Island. The stratigraphic relationships between samples have already been illustrated in Figure 4.9. Table 6.5 tabulates the list of the fossil Coleoptera recovered.

6.5.2 Age of the deposit.

Two AMS dates were obtained for this sequence (see Table 6.1). Sample 18, (160-172 cm, 60 cm. from the base) was dated to 2700-2350 cal BC (3990 ± 60 BP, BETA-91800), and sample 9 (115-120 cm.) was dated to 1130-840 cal BC (2820 ± 50 BP, BETA-91799). The basal date, from the black amorphous peat, corresponds reasonably well with other basal dates from Hatfield Moors.

6.5.3 Results

The samples from LIND B contain a range of very well preserved insects. Charred material was noted from the lower two samples (18 and 15) during processing. Members of the Carabidae, Dytiscidae (particularly of the genus *Hydroporus*), Staphylinidae and Scirtidae are particularly well-represented. Figure 6.6 illustrates the insect habitat categories represented. All species recovered are on the current British list (Kloet and Hicks, 1977), although *Pterostichus angustatus* has been regarded as an introduction earlier this century (Hyman, 1992). Its presence as a fossil in deposits dated to sometime after *c.* 2700-2350 cal BC (*c.* 4,000 B.P.) is significant.

6.5.4 Environmental reconstruction

6.5.4.1 The woodland communities

The most striking aspect of this assemblage is the absence of taxa associated with ancient woodland, especially the *Pinus* loving species that are common elsewhere on Hatfield Moors (e.g. HAT 3 and 4). Given the date of this sample, *c.* 4,000 BP, this is quite surprising, as many other areas of the Moors appear to have had *Pinus*-dominated woodland growing in the vicinity. There are just two species that could suggest the presence of *Pinus*, although their presence could also be attributed to dry *Calluna*-heath conditions. *Pterostichus angustatus* is a predatory species found on dry heaths and on litter below *Pinus sylvestris* (Hyman, 1992). Lindroth (1974) considers that it is rarely found on heaths without evidence of burning, although there are recent records from unburnt heaths on sandy or peaty soils (Luff, 1998). This sample's flot contained burnt fragments of plants. *Cymindis vaporariorum* is an unusual find, as it is usually considered montane, often occurring on sandy moraine (Lindroth, 1974), although Hyman (1992) lists its preferred habitat as peat and heather moorland, especially on sandy soils. Koch (1989) also lists light, dry conifer woods. All these habitats would have been present, especially on the exposed sand dunes where *Pinus* was growing.

The evidence for *Pinus* growing in the vicinity is, at best circumstantial, and does not include any of the saproxylic species.

6.5.4.2 The heathland communities

The feature that makes this assemblage different from many of the others is the high numbers of ground beetles that are associated with sandy heath conditions. In the lower two samples the sandy heath element is largely represented by the presence of the heather weevil, *Micrelus ericae,* although *Bradycellus ruficollis* and *Olisthopus rotundatus* are also present in small numbers. These two species increase dramatically within samples 12 and 9, particularly in sample 12, where 34 individuals of *B.ruficollis* were recovered. This is a stenotopic species of *Callunetum*, and is only found where there is a developed humus layer under *Calluna* (Lindroth, 1945). It is often associated with *Olisthopus rotundatus* (Eyre and Luff, 1990), which has very similar habitat requirements. The increase in the former species' numbers may indicate that the ground cover of heather had increased by this time, in comparison with earlier samples (Eversham, *pers. comm.*). Butterfield and Coulson (1983) found this species occurring on dry heath; the apparent increase in numbers of individuals of this species clearly highlights the importance of this element. *Bradycellus harpalinus* is also present, an exclusively sandy ground species, often under *Calluna* (Lindroth, 1986). *Dromius linearis* is a warmth-loving species that is usually found on dry, usually sandy soil, often on coastal sand-dunes (Lindroth, 1949, 1974). Champion (1909) also records it under *Pinus*. It is not difficult to see why Hatfield Moors, with its extensive sand dune system, should have been an attractive site for many of these species. The *Calluna* feeder, *Micrelus ericae*, continues to be an important faunal element, as does the chrysomelid *Altica ericeti/britteni*. The increased diversity of heathland insects in this sample suggests that the heathland element in the fauna had become more established and more diverse, possibly with new and different microhabitats.

There also appears to have been a change by the time the next sample (9) was deposited, with a decline in the range of species represented. The continued importance of heathland is reflected in comparatively high numbers of the rove beetle *Olophrum piceum*, one of the more common heathland species, which is also predatory upon the heather feeder, *Micrelus ericae* (Delany, 1960). It is difficult to suggest with any certainty whether these faunal changes reflect actual landscape changes. Heath is still clearly an important landscape element, although the range of available habitats may have declined. This data may reflect the dynamics of the mire, as different habitats expanded and contracted across the mire.

6.5.4.3 The acid-loving communities

Acid conditions are indicated from the beginning of peat initiation. *Acidota crenata* was present within the two basal samples, a species that is often found often in bogs, in *Sphagnum* and *Carex*, although it can also be found in woods (Koch, 1989). Several ground beetles associated with acidic conditions are present in sample 15. *Bembidion humerale* is a rare species typical of lowland peat bogs, a species restricted to the Humberhead peatlands. The adults often live in damp hollows by peat pools. (Hyman, 1992). *Agonum sexpunctatum* is frequently found in bogs, often on open moist, sparsely vegetated peaty soil with *Carex* or grasses, on bare spots (Lindroth, 1974), a similar location to the previous species. *Philonthus nigrita* occurs in bogs and swamps, in wet *Sphagnum* and plant debris (Koch, 1989). The evidence supports the idea of increasingly acid conditions in this area of the mire, together with the expansion of heath.

There is little or no indication of minerotrophic conditions. Figure 6.8 shows an increase in non-acid wetland species in the upper two samples examined, but this appears to be the product of the classification system. It is worth noting the behaviour of the ground beetle *Pterostichus diligens* through the samples. This species is often associated with bogs, although it is found on all kinds of moist ground (Lindroth, 1974). For the purpose of the analysis, this species was placed within the non-acidic category, since it is found in other moist locations, as well as bogs. Its presence explains the increase in the non-acidic category in sample 12 and 9. However, when compared with other acid indicator species, it appears the beetle was reacting positively with the acidic conditions, although it is not considered an acidophile. A similar pattern is seen very clearly at the HAT 4 site with this species. An explanation could be that rather than being an acid-*loving* species, *P. diligens* is more *tolerant* of acid conditions than others, allowing its population to expand (e.g, lack of competition or predation).

6.5.4.4 The aquatic community

In the lower samples, there are a small number of individuals associated with aquatic habitats, such as members of the genus *Hydroporus*. There is a large increase in these water beetles within samples 12 and 9, including many individuals of *H.pubescens*, a species found in all types of stagnant water bodies, often in shallow, grassy temporary pools (Nilsson and Holmen, 1995), although Koch (1989) records it in leaf-rich standing woodland ponds and bog pools. The absence of some of the larger dytiscid taxa, would suggest that any body of water in the vicinity was probably relatively small. The well-humified nature of the peat from these samples also indicates that the bog at this stage was relatively dry. Alteration of the hydrological regime is likely to be a major contributor to any changes in decomposition rates and hence humification. In contrast, sample 12, in particular, came from an unhumified *Sphagnum* peat deposit and must have developed during a period of wetter hydrological conditions, and been deposited fairly rapidly. This expansion of wetter habitats is supported by the increase in the *Hydroporus* species as well as the increased presence of the larger water beetles, such as *Agabus bipustulatus, Ilybius subaeneus* and *Ilybius aenescens*, the latter a species of acid water, deeply flooded with *Sphagnum* (Friday, 1988). All this supports the idea of increasingly ombrotrophic conditions.

6.5.4.5 The hygrophilous community

Members of the Scirtidae family, together with the predatory Staphylinid beetles would have inhabited the damp plant litter and/or moss in and around these pools. The increase in wet conditions noted in sample 12 is evident amongst the hygrophilous genus *Cyphon*, which increases throughout the upper two samples, together with other wet-loving taxa (e.g. *Dyschirius globosus*). The damp *Sphagnum* and plant litter around the pools created suitably wet habitats for staphylinids such as *Stenus* spp., *Lithocaris* spp., *Lathrobium fulvipenne*, *L. longulum* and *Biblopectus ambiguus,* which are found in bogs, *Alnus* carrs, in *Sphagnum* and in detritus of *Phragmites* (Koch, 1989). It is noticeable that whilst these species were recovered in numbers from the upper two samples, they were almost entirely absent from the lower two samples, confirming the impression that the two upper samples reflect much wetter conditions.

6.5.4.6 The decay community

There is some indication of decaying animal (dung) and plant debris, which appear fairly constantly through the samples. Thus, *Cercyon haemorrhoidalis*, is very common in cow dung (Skidmore, 1991), although it is also found frequently in rotting plant debris (Hansen, 1987). The presence of decaying animal or plant matter is also suggested by the occurrence of staphylinids such as *Philonthus* spp., *Omalium rivulare* and *Platydracus fulvipes*, which are found in herbivore dung (Skidmore, 1991). It is quite possible that all or most of these species were living in rotting vegetation surrounding bog pools. If the presence of dung is hinted at, it may indicate a sporadic presence of large herbivores, such as deer, either passing by or on Lindholme Island.

6.5.5 Diversity of the samples

Figure 6.7 shows species diversity for LIND B. The diversity values of these samples appear to reflect the fluctuating conditions which were suggested by the insect evidence. Thus, the lowest sample displays a very low diversity of species, perhaps a reflection of the higher proportion of acid wetland species in this sample. In contrast, sample 15 contained a much higher index of diversity, which is explained by the increase in heath communities. The two succeeding samples indicate a decreasing diversity of species.

6.5.6 Environmental interpretation

A range of heath and sand-dune loving taxa, reminiscent of wet heaths were recovered. Water levels appear to have fluctuated, reflecting shifts between drier and wetter conditions. Had more samples been examined, it might have been possible to examine if these dry/wet events were cyclical. Ombrotrophic conditions were evident within the basal samples. There is a very evident lack of "*Urwaldtier*" species. The lack of pinicolous species is surprising, particularly given the proximity of the samples to areas where *Pinus* was known to have been growing on the developing mire, as well as the proximity of Lindholme Island. This could reflect two possible events. Firstly, that the assemblage represents a very localised environmental picture, and reflects the fact that there were few trees in the vicinity. Secondly, the basal sample represents a deposit about 65 cm. from the base and could have been created at a time when *Pinus* was no longer growing on the surface of the mire. This latter interpretation seems unlikely, given the dry conditions implied by the assemblage, as well as the well-humified nature of the peat deposit (assuming well-humified peat reflects a drier phase of the mire, *cf.* Barber, 1981): such conditions would appear ideal for the growth of *Pinus*. It would thus seem more likely that *Pinus* was growing in the area, as hinted at by some taxa, but that the assemblage represents a very localised environmental picture.

The assemblage from LIND B lacks a faunal element associated with aquatic vegetation and water margins. The lack of members of the families Hydraenidae and Hydrophilidae, many of which are typical of small detritus pools, with abundant leaves and amphibious plants, would confirm this idea. There appears to have been the presence of plants such as *Phragmites,* as well as an abundance of *Sphagna* species, and *Calluna* appears to have been a very important vegetational component.

6.6 Tyrham Hall Quarry, Hatfield Moors, (TYRHAM)

6.6.1 Introduction

A series of 6 contexts were sampled from TYRHAM, comprising 877 MNI, belonging to 148 different taxa, across 23 different families. The purpose of analysing these samples was primarily to examine the nature of the woodland at Tyrham Hall Quarry, as well as elucidate mire initiation in this area. All samples except one were associated with *Pinus* rot holes ("1, 2A, 2B, 3 and K"). The remaining sample came from a *Quercus* rot hole ("Oak"). Much of the material came from trees that had visible charring upon their surfaces and all samples, except 2A and 2B, contained abundant charcoal. Table 6.6 tabulates the list of fossil Coleoptera from Tyrham Hall Quarry.

6.6.2 Age of the contexts

The fossil woodland at Tyrham Hall has been dendrochronologically dated by Boswijk (1998). There were at least two different phases of tree growth in this area. The *Quercus* from which the "Oak" sample was removed was dated to 3618-3418 BC (THQ25) (Boswijk, 1998). However, the majority of the samples came from the *Pinus* woodland which was dated to 2921-2445 BC, (TM01 chronology), 500 years later. One of the insect samples (K) was removed from a *Pinus* which was taken for dendrochronological dating (THQ 12); unfortunately, no date was obtained for this tree, which was slow growing, but was probably contemporary with the rest of the woodland (Boswijk, *ibid.*). Assuming the majority of the *Pinus* were contemporaneous, this roughly dates the *Pinus* faunas to c. 2921-2445 BC.

6.6.3 Results

The samples from TYRHAM included a range of exceptionally well preserved insects. There is an abundance of very rare and non-British species, particularly from the Curculionidae and Cucujidae families. Amongst the other families represented were Carabidae, Dytiscidae, Hydrophilidae, Staphylinidae, Chrysomelidae and Scolytidae. Many of the fossils were still articulated, particularly those from sample 1, suggesting that most of the contents of the rot hole were probably *in situ* remains.

6.6.4 Environmental reconstruction

6.6.4.1 The Quercus woodland, c. 3618-3418 BC

Figure 6.8 shows the composition of the *Quercus* sample, whereas Figure 6.9 shows the general proportions represented by the wood and total larger habitat categories. Although most of the analysis for this research has tried to not use proportions, it was felt that a graphic representation of the sample's proportions might be useful for interpretational purposes, especially as the material from Tyrham represent context samples, rather than sequential samples.

The most important categories represented are the saproxylic, damp woodlands, non-acid wetlands, aquatic and hygrophilous communities. There is a marked absence of species associated with *Calluna* heath and with acid conditions. This sample provides an insight into the nature of the pre-peat landscape and represents the oldest sample examined for its fossil insect fauna on Hatfield Moors.

There is a small number of species associated with the *Quercus* woodland, such as the *Quercus* leaf miner, *Rhynchaenus quercus*. The larvae and adults of *Bitoma crenata* are predatory under loose, dry, sun-warmed bark of all species of tree (Palm, 1959), particularly dead *Fagus* and *Quercus* in the early stages of decay, as well as on *Betula* (Alexander, 1994). Lundberg (1984) claims *B. crenata* is attracted to fire-damaged woodland; the sample contained abundant charcoal. However, neither Ahnlund and Lindhe (1992) nor Wikars (1992) record it from burned forests in Sweden, and it could be a species which is attracted to a range of disturbance areas.

Two individuals of *Rhyncolus ater* are also present. In Britain, this species is associated with *Pinus sylvestris* (Alexander, 1994). In mainland Europe, however, it is as common in deciduous as coniferous wood and is a secondary coloniser, developing in rotten wood of varying hardness and moisture content (Palm, 1951; 1959). Its presence in a *Quercus* rot hole suggests strongly that at Tyrham it was associated with deciduous wood.

No species recovered are typical of acid peatlands, but rather those associated with fens and *Alnus* carr, such as *Pterostichus nigrita*, as well as *P. diligens*, which is found on peaty substrates (Eyre and Luff, 1990). The staphylinid *Olophrum fuscum* is found in detritus of *Phragmites*, *Carex* and *Juncus*, under damp leaves and moss, often in marshes and *Alnus* carr (Koch, 1989). *Plateumaris sericea* is typical of fen conditions (Stainforth, 1944; Bullock, 1993).

The importance of the aquatic element within these samples is illustrated in Figure 6.9. Most of this component comprises *Hydroporus* spp., which are usually associated with small pools. However, the presence of the larger Dytiscidae *Ilybius guttiger* and *Agabus unguicularis* suggests that some areas of water would have been sizeable and probably permanent. Both species are often associated with mesotrophic conditions, being typical of permanent pools in fens and lowland bogs (Merritt, 1995) with dense vegetation (Nilsson and Holmen 1995). No species of acid aquatic conditions were recovered.

This fauna is closely associated with its sampling context, and is indicative of damp *Quercus* woodland. Other trees were also growing in the vicinity, such as *Alnus* and *Betula*. It is unclear whether *Pinus* was growing in the area. The absence of insect species directly associated with *Pinus* does not preclude its presence. Dead wood was abundant. Permanent pools with rich littoral vegetation were in the immediate vicinity. Both the damp woodland and the pool edge area would have been attractive to a range of hygrophilous species such as members of the Scirtidae and some Staphylinidae family. The *Quercus* probably became submerged within a pool upon its death.

6.6.4.2 The Pinus woodland, 2921-2445 BC

Figures 6.10-6.14 show the composition of the individual samples examined from the *Pinus* woodland. The following discussion will briefly look at each sample, but will discuss the environmental implications using the complete assemblage, since the samples all relate to the same period of the woodland, providing a broad picture of environmental change. Accordingly, Figure 6.16 also illustrates the different habitat proportions (Wood categories and Total categories) represented by the *Pinus* samples.

Sample 1 contains a very high number of dead *Pinus* wood species as well as some dead deciduous wood dependant taxa and probably represents beetles which had died *in situ* within the rot hole. There is a small number of heath-loving species and a mixture of mesotrophic and ombrotrophic-loving beetles. There is a good range of aquatic species, particularly acid-loving ones. Sample 2A and 2B came from different rot holes of the same tree and contain some species associated with wood. There is a mixture of acid and non-acid loving taxa, as well as a range of hygrophilous and aquatic species, mainly those species which live in all types of bogs and aquatic generalists, rather than acid tolerant taxa. Sample 3 is very similar in composition to 2A and 2B, with a mixture of mesotrophic and ombrotrophic elements, but also with a heath component. The last sample, K, has many similarities with sample 3, but has more saproxylics.

Broadly speaking, the *Pinus* samples display many similarities and appear to be composed of two faunal elements. One part of the assemblage relates to habitats directly associated with the wood, the other part to the depositional environment into which the trees became submerged. Figure 6.16 provides a visual impression of those different habitats: the aquatics clearly dominate the assemblages, comprising about 47% of the overall *Pinus* assemblage. Wet-loving species take up another important part of the assemblage. Acid and non-acid habitats take up roughly the same proportion, with saproxylic species taking up about 13% of the assemblage, largely dominated by decaying coniferous wood-loving species.

The species provide information regarding the nature of the woodland at Tyrham during this period. *Quercus*, in addition to *Pinus,* was growing in this area. *Rhynchaenus quercus*, the leaf miner on *Quercus* and *Acalles roboris,* often recorded from *Quercus* litter, are both present (Hyman, 1992). The non-British *Urwaldrelikt Prostomis mandibularis* is often found in large numbers with its larvae (Reitter, 1911), mainly in decayed red rotted *Quercus* (Horion, 1960), typically in areas of primary woodland Palm (1959). However, singly, it can be found in decaying wood of *Pinus* (Koch, 1992) and since just one individual was recovered from sample 2A, this species could have been feeding on fungoid *Pinus* rather than *Quercus*. The scolytid *Dryocoetinus villosus* was recovered from the same sample. This species lives in thick *Quercus* bark, especially on large stumps and older trees damaged by fire; it also occasionally occurs in thick *Fagus* bark (Palm, 1959). There were no signs of charring on the outside of this tree, nor was any charcoal noted within the sample. Sample 1, which came from a charred tree, contained abundant charcoal; the ground beetle *Dromius quadrinotatus* is present in this sample. This species is usually found on *Pinus* (Lindroth, 1974) and Palm (1959) considers it a fire species.

One individual of the non-British *Urwaldtier Rhyncolus punctulatus* is present (sample 2A). This is a beetle that is found in hollow deciduous trees, often in *Quercus*, as well as in conifers (Reitter, 1916; Palm, 1959; Folwaczny, 1983). It is often found with *Phloeophagus lignarius*, recovered from the same sample, in dry wood (Palm, 1959). *Fraxinus excelsior* is the host of the bark beetle *Leperisinus varius*. The rare RDB 2 elaterid *Ampedus rufipennis* is also present. This is a species which is found in mouldy deciduous wood, predominantly on *Fagus* (Horion, 1953; Palm, 1959), although it can also live on *Betula*, a tree which was certainly growing, as the presence of its leaf miner, *Rhynchaenus rusci*, suggests.

There is a range of species which live both in deciduous and coniferous wood, such as members of the genus *Rhynchaenus* and the scolytid *Xyleborus saxeseni*, which live in galleries within thick bark of freshly dead or dying *Quercus*, *Fagus*, *Betula*, *Alnus* and other trees, including conifers on the Continent (Palm, 1959; Alexander, 1994). However, given that the beetle came from sample 1 (as well as sample 2) and the fact that this assemblage's preservation was strongly reminiscent of an *in situ* rot hole, it is likely that the scolytid was boring into *Pinus* rather than deciduous wood. The same observation can be made with regard to the presence of the *Urwaldtier Dryophthorus corticalis* within this context. The high numbers recovered and the intact state of preservation of this insect suggests it was feeding and breeding within the *Pinus* rot hole. Despite the fact that in Britain this species is usually only associated with *Quercus* (Donisthorpe 1939; Hyman, 1992), the beetle is frequently recorded in coniferous wood on the Continent (Reitter, 1916; Palm, 1959; Koponen and Nuorteva, 1973), often in high numbers. As a fossil, the species is closely associated with *Rhyncolus* species (Whitehouse, 1997a), and this association is noted within the European literature (Palm, 1959). Members of this latter genus, including the non-British species *R. elongatus*, *R. sculpturatus* and the British *R. ater*, are also present within this sample, appearing to have been attracted to the rotting *Pinus* in great numbers. These *Urwaldtiere* are also strongly associated with each other (Palm, 1959).

Most of the species described above are those which attack wood during early stages of infestation, largely bark beetles and weevils. The following phase is characterised by the presence of sap wood feeding insects and the appearance of several large predators. During the final phase, many fungus-feeding insects invade the wood, becoming the most overwhelming type of species (Wallace, 1953). At Tyrham Hall Quarry there are also some species associated with the second phase, such as predators upon bark beetles, *Rhizophagus ferrugineus* and *Cerylon histeroides*, which are found on coniferous and deciduous trees. *Ostoma ferrugineum* burrows in coniferous wood when it is fungoid and rotting, often when attacked by the fungus *Polyporus schweinitzi* (Skidmore, *pers. comm.*, 1998). The specific polypore species decaying the wood are important factors affecting the hosts of many individual saproxylic species (Kaila *et al.*, 1994). Species associated with moulds, *Lathridius minutus/pseudominutus* and *L.* (?) *anthracinus*, probably also represent this phase of wood decay.

There is also a small assemblage of species associated with damp woodland conditions, such as *Agonum obscurum* and *Trechus obtusus*, species typical of swampy deciduous woods (Lindroth, 1945). *Pterostichus strenuus* is found in the drier parts of *Alnus* swamps, in fen woodland and in deciduous woodland pasture, chiefly among leaves, moss and brushwood (Lindroth, 1945).

There are several species associated with heath. *Acalles ptinoides* is often found in sandy regions, deciduous woodlands and heaths (Koch, 1992), often beneath leaf litter and *Calluna* (Hyman, 1992). The presence of the heather feeder, *Micrelus ericae*, often in some numbers, corroborates the presence of this plant. There is also the presence of several beetles typical of *Callunetum*, such as *Bradycellus ruficollis*, *B. harpalinus* and *Xantholinus linearis*.

In addition to heath species, there are some beetles which provide insight into the under-storey and open areas of the *Pinus*-dominated heath. *Anthonomus* (?) *rubi* is found on rosaceous herbs and shrubs, mainly *Fragaria*, *Geum*, *Rosa* and *Rubus* spp. (Morris, 1977). Members of the genera *Apion*, *Sitona* and *Ceutorhynchus* would be found on grasses and herbs in open areas. *Chaetocnema concinna* is often associated with *Polygonum* and *Rumex* species (Bullock 1993), although it can also be found in reed swamp at edge of ponds, feeding on Cruciferae (Richards, 1926). *C. hortensis* is oligophagous on Poaceae (Koch, 1992) and on *Plantago* species (Lane, 1992).

The next part of the assemblage comprises aquatic or those associated with "wet" habitats. It is difficult to know what portion of this assemblage was contemporaneous with the *Pinus* woodland, and what became incorporated within the rot holes in peat when the trees began to be buried by the growing mire. It seems reasonable to assume that some were present when the woodland was coming to the end of its life, as well as representing some deposited when the woodland was being buried.

There is a good range of species that are often found in mesotrophic peatlands, such as *Pterostichus nigrita/rhaeticus*, *P. minor*, *P. diligens* and *Agonum fuliginosum*. The byrrhid *Curimopsis nigrita* is a lowland peatland specialist, which is today confined to Thorne and Hatfield Moors and lives amongst *Sphagnum* and *Calluna* litter (Hyman, 1992). It indicates the presence of ombrotrophic conditions, either when the trees were dying or shortly afterwards. The mixture of mesotrophic and ombrotrophic conditions is also evident amongst the beetles that live on aquatic vegetation, with *Plateumaris sericea* and *P. discolor* present, although the latter species is more abundant. The former species lives on aquatic plants such as *Typha latifolia*, *Iris pseudacorus*, *Schoenoplectus lacustris*, *Bolboschoenus maritimus* and *Sparganium erectum* (Stainforth, 1944) as well as on *Carex* and *Nuphar* species (Bullock, 1993). *P. discolor* is associated with ombrotrophic conditions, living on *Eriophorum*, *Sphagnum* and on *Carex* species (Stainforth, 1944; Bullock, 1993). Increasingly wet conditions were enjoyed by a range of different species, such as the ground beetles *Dyschirius globosus*, *Bradycellus verbasci* and *Trechus rubens*. The latter is found in wetlands and margins of ponds and rivers, often near coniferous woodland (Hyman, 1992). Hygrophilous species that are associated with plant litter are also present, although not in particularly large numbers, for example, various staphylinids and the hydrophilid *Megasternum obscurum*.

The mixture of habitats described is reflected amongst the aquatic communities. There is a range of species that live in many different aquatic habitats, as well as those which live in all types of bogs, such as *Hydroporus scalesianus*, *H. pubescens* and *Agabus chalconatus*. There are also some species which are associated with non-acid conditions, although these make up a very small proportion of the assemblage. These include the RDB3 fen-loving hydrophilid *Limnebius aluta* and the RDB1 species *Graphoderus* (?) *bilineatus* which lives in fen drains (Shirt, 1987), mainly in deep ponds and lakes, generally with dense marginal vegetation (Nilsson and Holmen, 1995). In contrast, there are many more acid-loving aquatics, although most originate from one sample (1). This category includes *Hydroporus tristis*, *H. melanarius* and *H. gyllenhali*, all of which appear to be strongly associated with more acid conditions (Friday, 1988). Larger Dytiscidae are associated with all of the above aquatic habitats. *Ilybius aenescens* favours acid bog pools containing deeply flooded *Sphagnum* and fringed with *Juncus* (Merritt,1995).

The evidence supports the impression of deep pools, associated with low numbers of species typically found in shallow detritus pools. There are several species suggestive of slowly moving water, such as *Agabus guttatus*, mainly found in springs and various smaller running water bodies, frequently under stones in small forest streams (Nilsson and Holmen, 1995) and *A. melanarius* which is found in shallow spring-fed, almost plant-free pools (Friday, 1988; Koch, 1989).

6.6.5 Diversity indices

The diversity indexes for these samples are shown in Figure 6.15. The *Quercus* sample shows the lowest diversity. This is probably explained by the context sampled, which represents mainly frass and dried peat, rather than the contents of a rot hole, which the other samples came from. The other samples displayed a high diversity value, as expected with insect faunas from woodland and minerotrophic mire (Elton, 1966; Roper, 1996).

6.6.6 Environmental interpretation

6.6.6.1 The Quercus woodland

Looking at Figure 6.9, it is clear the sample represents two broad assemblages, the aquatic and hygrophilous community and that associated with the *Quercus*. The aquatic and associated community became incorporated into the deposit because of the depositional environment, into which the *Quercus* fell upon death. The range of saproxylic species suggest that the *Quercus* was not growing in isolation. Very little is known about the mobility of saproxylic invertebrates, although it is generally accepted that many have very limited powers of dispersal (Warren and Key, 1991). The assemblage at least hints at the presence of other tree taxa within the vicinity. Something unusual must have happened to the *Quercus* for its preservation to have occurred, especially given the fact that the main preserved palaeowoodland, the *Pinus* woodland, grew on the site about 500 years later. It seems likely that the *Quercus* was submerged into a permanent and probably deep pool upon its death. The dendrochronological work on the tree did not indicate any signs of stress upon this mature tree, which had lived about 200 years. The fauna also indicates fen conditions, which may have been present during the *Quercus*' life span, or may reflect conditions immediately after its death. The submergence of the *Quercus* into water may explain its death, perhaps in response to a rising water-table, which may have created temporary flooding of the area, causing death of trees. However, it must have been limited in extent, otherwise a range of other tree remains would have preserved from this period.

6.6.6.2 The Pinus woodland

The fossil insect faunas suggest that *Pinus* was an important component in the areas where sandy substrates created suitable conditions for heathland to develop. In addition to *Pinus*, there appears to have been other tree species growing, certainly *Quercus*, *Fraxinus*, *Betula*, probably *Alnus* and possibly *Fagus*. Several faunal elements may have been attracted to charred trees. Areas of heath and possibly grassland were also present. There is an interesting mixture of fen and ombrotrophic indicating species, reflected both in species living on aquatic plants as well as amongst the aquatic communities. Within this element, there are also species indicative of deep pools, with areas of open and flowing water.

Several factors could explain the mixture of the different species associated with the *Pinus* samples. Firstly, they could all mirror the environment when the *Pinus* trees were becoming submerged by the mire, reflecting a mixture of mesotrophic conditions, with a stronger ombrotrophic element. Alternatively, the fen elements could represent conditions when the *Pinus* forest was growing in an increasingly wet, swampy environment. It is tempting to correlate the impression of moving water and deeper water environments with an episode of ground-water flooding, probably caused as a result of a rising water table. With expanded areas of water, the *Pinus* forest could no longer survive and the trees became submerged within pools. The excellent state of preservation of the trees indicates that were buried by the mire at a rapid rate.

Ombrotrophic conditions may have been present before the death of trees, but if not, probably occurred soon afterwards.

6.7 Similarity indices (Jaccard's coefficient)

Table 6.7 shows the Jaccard's coefficients for the Hatfield Moors samples. The most striking aspect of the table relates to the low correlation of similarity (0 lowest, 1 highest). The highest similarity displayed by the coefficient is 0.39, but most samples show a similarity between 0.07-0.18. The coefficient confirms the impression gained from the detailed descriptive analysis of the samples: that the samples are generally dissimilar. This result highlights two points. The faunal samples display some of the ecological complexities evident across a mire such as Hatfield Moors, making each sample unique, and highlighting the dynamic aspect of this system. Secondly, they illustrate a potential methodological problem and justify the approach taken in this research. The faunas indicate the benefits of looking at multiple locations across a mire, and suggest that interpretations based upon just one succession or site may be misleading, particularly when large mire sites are being studied. This is also true when other palaeoecological techniques are being used. This should not be surprising, given the essentially local information derived from palaeoentomological assemblages.

6.8 Diversity indices

The diversity values for the assemblages from Hatfield Moors show fairly consistent internal values with their environmental types. Higher values seem to be characteristic of assemblages from forest and minerotrophic mire (e.g. Tyrham, HAT 4). The values obtained are consistent with values reported by Paviour-Smith and Elbourn (1993), who used Fisher's α to measure the diversity of fauna of dead and dying wood from Wytham Woods, near Oxford. They reported a diversity value of 54 for their assemblage, which falls within the range reported from the basal forest samples from Hatfield Moors (e.g. HAT 3 (17); HAT 4, zone 1; TYRHAM samples).

On Hatfield Moors, mesotrophic mire samples tend to be represented by slightly lower values, whereas the ombrotrophic samples display much lower values, in the region of 18-10 Fisher's α. Such a result is to be expected, as acid raised mire conditions can only be tolerated by a small number of specialised invertebrate and plant communities (Ball, 1992). The results are consistent with those from other mire sites (Roper, 1993; 1996; Jordan, 1995). Roper (1993; 1996) found that the transformation of minerotrophic fen into ombrotrophic bog on Thorne Moors caused a dramatic drop in insect diversity.

When Roper's index figures are compared with those from Hatfield, it is clear that the diversity figures are generally higher and are closer to those which she attributed to the minerotrophic phase of the bog. Several factors probably explain this difference. One undoubtedly may be connected with the heath element within the Hatfield faunas, even within ombrotrophic samples. In addition, woodland, particularly *Pinus*, appears to have been an important element within the landscape at Hatfield, up to the present day. Both these factors would explain the greater diversity of the faunas from Hatfield Moors.

6.9 Species of particular note

An outstanding range of rare and endangered species was recovered from the deposits at Hatfield Moors. A glance at Table 6.8 highlights the number of rarities present. These include seven non-British species, five RDB1, eight RDB2, five RDB3, five NA and thirty-five NB species. The majority of these are composed of saproxylics and specialists of wetlands. There were also twenty-two new fossil records. Given the high number of species represented and the fact that many overlap with those found at Thorne Moors, Hayfield Lodge Farm and Misterton, comments on these species' biology and biogeographical implications are felt to merit a separate chapter (see Chapter 12). The following chapter attempts to integrate all the palaeoecological information from the sites examined and discusses the environmental history of Hatfield Moors, without dwelling too much on the biogeographic significance of some of the species recovered.

CHAPTER VII: LANDSCAPE DEVELOPMENT OF HATFIELD MOORS; A FOSSIL INSECT PERSPECTIVE.

7.1 Introduction

The palaeoentomological record from Hatfield Moors highlights a series of environmental changes over the period from *c.* 3618 BC (dendrochronological date, [Boswijk, 1998]) to *c.*560-680 cal AD (1405 ± 45 BP, SRR-6120), spanning about 4200 years. The complete period is not represented at any single site, but is represented if all sites are considered. Unfortunately, one of the sequences (HAT 4) appears to have been truncated by peat cutting representing a gap within the palaeoecological record. Figure 7.1 illustrates the chronological relationship between sites and samples. Table 7.1 presents a summary of the different vegetational and trophic stages represented by the mire's insect fauna.

7.2 Period *c.* 3618-3418 cal BC

This period is represented by the single sample from a *Quercus* at Tyrham Hall Quarry, which lived from *c.* 3618 BC and died sometime after 3408 BC (Boswijk, 1998). The presence of other undated *Quercus* on Hatfield imply there may have been contemporary trees. This woodland probably persisted in the area until the development of *Pinus* woodland, but it was either not preserved within the mire deposits or not sampled. The tree was contemporaneous with the *Quercus* woodland on Thorne Moors (3777-3017 BC), probably the relic of widespread forest growing across the Humberhead Levels (Boswijk, 1998). The insect evidence indicates that in addition to *Quercus*, scattered *Alnus* and *Betula* and possibly *Pinus* were growing, indicative of damp, deciduous fen woodland, although areas of heath also appear to have been important. Species typically associated with late successional habitats such as dying and dead wood suggest that the woodland was *Urwald.*

There is no contemporary palynological evidence for this period. The podzol noted during field survey suggests that a soil had developed in the area, prior to peat formation, although this was no longer visible in section. The podzol suggests that the sandy soil was more free-draining prior to peat formation, although eventually the soil could have affected drainage through the blockage of water percolation. Pollen analysis on material directly above the podzol suggests a wet *Calluna* heath (Dinnin, 1997c), although it should be noted that the sediment taken for analysis constituted a thin band above the podzol and may relate to the initial stages of peat formation.

7.3 Period *c.* 3300-2445 cal BC

This period is represented by samples from the *Pinus* woodland at Tyrham Hall Quarry, the basal samples from HAT 3 and the basal sample at LIND B.

Five hundred years later, the *Quercus* woodland at Tyrham was superceded by an open *Pinus* woodland (2921-2445 BC), with a high density of trees. Dendrochronological work indicates that the trees were long-lived (many of the trees exceeded 150 years, the oldest tree living for over 336 years) and appear to have been growing in a nutrient poor, but generally stable environment (Boswijk, 1998). The woodland had a pronounced mixed age structure and was typical of an old, established woodland, where new growth was also being sustained.

The fossil insect data strongly corroborate the dendrochronological evidence. There were abundant species associated with undisturbed ancient woodland (or *Urwald*), many living on mature, decaying and dead *Pinus* wood, which was the dominant wood taxon. Insects associated with moss and raw humus suggest an optimal environment which would have allowed the germination of *Pinus* seedlings. The woodland probably resembled a sandy *Pinus-Calluna* heath, with scattered *Quercus*, *Fraxinus* and *Betula*.

There was a steady decline in trees over a *c.* 450 year period, with some trees showing signs of extreme stress (Boswijk, 1998). Boswijk (*ibid.*) suggests this may have been induced by environmental changes such as flooding, drought, insect attack or competition by other trees. The insect faunas contain no indicators of large-scale insect attack, although such an event might be difficult to detect in the palaeoentomological record. In any event, various families besides Coleoptera attack trees in pest proportions. For instance, an attack by Lepidoptera has been linked to the mid-Holocene Hemlock decline in Eastern North America (Bhiry and Filion, 1996). However, the fossil insect evidence highlights increasingly wet ground-conditions, which would have reduced the stability of both living and dead trees and placed the woodland under increasing stress. Trophic conditions in the area were also changing rapidly, represented by a mesotrophic faunal community (a mixture of eutrophic and ombrotrophic taxa). Smith's (1985) work on plant macrofossils suggests an initial episode of flooding, indicated by the presence of *Sphagnum cuspidatum* within profiles at HAT 1 and 2, sometime around 2900-2620 cal BC (4180 ± 70 BP, CAR-168) and 3090-2890 cal BC (4335 ± 75 BP, CAR-254).

The death of the Tyrham *Pinus* trees occurred about 100 years after the main phase of *Pinus* growth at Thorne Moors (Boswijk, 1998). The demise, of the woodland, like at Thorne Moors, may have been in response to wetter conditions, but it is likely that the Tyrham trees were influenced by local edaphic factors, which may have delayed their response to more widespread changes (Boswijk, *ibid.*). The chronology at Tyrham ends at 2445 BC and there were no sampled *Pinus* after this date, although as Boswijk (*ibid.*) points out, some of the un-sampled *Pinus* could, of course, date after this period.

Kilham West's woodland was growing contemporaneously to Tyrham's, as the basal peat date of 3350-3030 cal BC (4480 ± 45 BP, SRR-6119) from HAT 3 suggests. The faunal evidence indicates that woodland continued growing on the developing mire and was characterised by undisturbed *Pinus-Calluna* heath, interspersed with trees such as *Quercus,* light-demanding *Fraxinus* and possibly *Fagus* and *Alnus*. *Fraxinus* is not normally associated with acidic soils, but the tree may have been growing on the margins of Lindholme Island, where there are more calcareous conditions. There was also an abundance of dead wood. Within just one sample, however, conditions changed from rheotrophic/mesotrophic to more ombrotrophic conditions, although some of the woodland species persisted. This transition appears to have occurred very rapidly, perhaps within just a few hundred years.

The basal deposits from HAT 3 consisted of black, well humified peat, with an abundance of mineral material, similar to those identified by Smith (1985) across Hatfield. These deposits are similar to the basal peats at LIND B, dated to *c.* 2700-2350 cal BC (3990 ± 40 BP, BETA-91800). The faunal communities from LIND B suggest ombrotrophic wet *Eriophorum vaginatum-Calluna vulgaris* heath (*cf.* Rodwell, 1991). The other samples from this location are not dated, but as the top part of the sequence dated to 1130-840 cal BC (2820 ± 50 BP, BETA-91799), they represent a continuous record covering the period between *c.* 2700-2350 cal BC and 1130-440 cal BC. The successive samples indicate increasingly wetter and ombrotrophic conditions.

The insect evidence supports the palynological evidence (Smith, 1985) (Figures 7.2a and b and 7.3a and b). Smith's (1985) site at HAT 2, (base dated to 3040-2890 cal BC, 4335 ± 75 BP, CAR-254) indicated the presence of a *Betula-Alnus* woodland. The woodland community had a well-developed *Sphagnum* layer, with *Calluna*. Smith (1985) found abundant *Eriophorum* remains during this early period, classifying this phase as *Calluna-Eriophorum* bog. At HAT 1, dated slightly later (base dated to 2900-2660 cal BC, 4180 ± 70 BP, CAR-168.), Smith (*ibid.*) suggested there was dense forest cover on the land surrounding Hatfield Moors, dominated by *Quercus*, *Corylus* and *Tilia*, with *Ulmus* and *Fraxinus* of less importance, and suggested that *Alnus* and *Betula* were possibly growing on the wetter areas of the growing mire. *Pinus* was locally abundant in the vicinity of Lindholme Island and on the bog margins (Smith, 1985). However, the insect and field survey data indicate that the woodland was more extensive, with *Pinus* and *Betula* growing on the surface of the bog in several locations, interspersed with at least *Alnus*, *Quercus* and *Fraxinus* on drier areas. Dense *Pinus* woodland was growing in the area of Tyrham and Kilham West and elsewhere, for instance Packard's south, where HAT 4 is located. There is no insect evidence for *Tilia* or *Ulmus*, which probably grew some distance away. Relatively high proportions of *Tilia* pollen were recorded from soil profiles at Kilham West (Dinnin, 1997c), which indicates that this was an important tree within the wider landscape, including perhaps on Lindholme Island.

7.4 Period *c.* ? cal 2,000 BC and following

Samples described in the above section would have spanned the temporal gap between about 2400 cal BC and 2000 cal BC, as not all samples are dated and often only basal dates are available. The base of LIND A is roughly dated to this period, on stratigraphic grounds (see section 6.4.2). The faunal assemblage suggested the presence of a wet *Pinus* heath, with areas supporting *Quercus*, *Betula*, *Fraxinus*, *Fagus* and possibly *Alnus*. The peatland and aquatic communities suggested mesotrophic conditions, but this was rapidly superseded by more ombrotrophic conditions, with *Betula* scrub and *Calluna-Eriophorum* communities forming the ground layer.

The palynological evidence represented by pollen zone HAT 1/B and HAT 2/C suggests a reduction in arboreal taxa, including *Pinus*, *Tilia*, *Ulmus* and *Quercus* and a small increase in herb taxa (Smith, *ibid.*). Smith (1985) also noted a marked *Pinus* decline in the palynological record, dated to *c.* 2200-1970 cal BC (3685 ± 65 BP, CAR-256). In addition, peat stratigraphy showed a marked charcoal layer at this horizon and elsewhere along the boring transect, dated to *c.* 2040-1780 cal BC (3570 ± 70 BP, CAR-169). Smith (1985) interpreted this zone as representing a phase of local clearance activity. However, whilst there may have been clearances away from the margins of the mire, some of the fluctuations in arboreal taxa may have been in response to changing local edaphic conditions, such as the increasing acidity. Species such as *Pinus* and *Quercus*, living on and in the vicinity of the developing mire, may have been affected in this way. Waller (1994) has argued that the reduction in *Tilia* pollen representation in diagrams may be a taphonomic product of the process of paludification, although it is also associated with human activities (*cf.* Turner, 1962; 1965). In addition, the charcoal horizons noted could be related to mire fires, rather than clearance activities (e.g. Simmons and Innes, 1987). Abundant charred *Calluna* seeds frequently occurred within deposits, including at LIND A. Smith (1985) noted the same feature at HAT 2. This strongly suggests charring occurred as a result of *in situ* surface mire fires. Smith's (1985) macrofossil's evidence indicates that the mire was relatively dry during this period, characterised by wet heath *Calluna-Eriophorum* communities and *Betula-Pinus* woodland, which may have been prone to fires during periods of seasonal dryness.

7.5 Period *c.* 1520-1390 cal BC to *c.* 1,300 cal BC

This period is represented by the basal deposits at HAT 4 (assemblage zone 1), dated to *c.* 1520-1390 cal BC (3165 ± 40 BP, SRR-6127). The faunal assemblage from this area contains rheotrophic fen species, together with those associated with mature, ancient *Pinus* woodland/heath. *Betula* was also growing on the developing mire, as its remains within the peat profile indicate (Tyers, *pers. comm.*, 1997). *Quercus*, *Fraxinus* and *Fagus* appear to have been growing and *Alnus* carr was an important component. The beetle fauna indicates a forest with many late successional habitats and an abundance of dead wood, with many species associated with primeval, undisturbed woodland. This community probably represents a habitat on the margins of the developing mire, a lagg fen community. Peat deposition in this southern area initiated between 1780-1055 calendar years (taking the maximum and minimum age-span between calibrated radiocarbon dates), after the *earliest* date for peat development on the Moors, at HAT 3 (3350-2930 cal BC [4480 ± 45 B.P., SRR-6119]). The record from this area represents the only site on Hatfield Moors where rheotrophic peat development occurred. Smith (1985) suggests that the lack of this phase elsewhere is related to the acid, nutrient-poor sands beneath Hatfield Moors. This is also one of the few areas where *Alnus* appears to have been growing, a tree known to have quite high nutrient requirements.

Palynologically, this period is represented within assemblage zones HAT 1/B and HAT 2/C, discussed above. Although Smith (1985) notes human activities in the form of clearances, there are no such indications within the entomofaunal record, suggesting that this site represents a local picture of environmental change.

It is interesting to note that the onset of peat accumulation at this site corresponds closely with Smith's recurrence surface HHL V, dated to 1610-1440 cal BC (3240 ± 70

BP, CAR-257), at HAT 2. At HAT 1 this episode is dated slightly later, to 1000-840 cal BC (2775 ± 65 BP, CAR-170), delayed presumably because of this site's position adjacent to the higher ground on Lindholme Island. Smith (*ibid.*) suggests this period is characterised by relatively damp or wet conditions, with the replacement of dry *Calluna-Eriophorum* communities with acid pool conditions in which *Sphagnum cuspidatum* and *S. acutifolium* are dominant, with areas of *Andromeda polifolia*. Whilst such vegetational communities may not have been present initially at HAT 4 (*c.* 3 km south-west of HAT 2), it is likely that increasingly wet and ombrotrophic conditions encouraged expansion of the mire into the areas of lagg fen.

7.6 Period *c.* 1,300 to *c.* 1,000 cal BC

This period is represented by insect assemblage zone 2 at HAT 4. The evidence suggests that the *Pinus* heath in this marginal area of the mire was becoming increasingly waterlogged and appears to have abruptly died out at the end of this period. Much of the insect evidence supports the impression of stressed and weakened trees. *Alnus* however, appears to continue to be a locally important component. Heath communities become important and there are large increases in aquatic taxa, with a mixture of fen and acid-loving species, suggesting a mesotrophic community. The sharp rise in aquatics suggests higher water levels, possibly due to flooding/run-off from the mire or rising ground-water levels, which presumably contributed to the onset of ombrotrophic conditions. It is possible that the increasing wetness noted at the recurrence horizon HHL V (section 7.5) (Smith, 1985) may have generated a "time delayed" flooding upon this marginal area of the mire. Palynologically, this period is still represented within assemblage zone HAT 1/B and HAT 2/C, described above.

A transitional phase is indicated when eutrophic fen and acid raised mire communities co-occur, where both communities are present over the bog or where transition to raised mire occurres in different parts of the bog surface at different times (*cf.* Korhola, 1992). Alternatively, transition to ombrotrophic mire may have occurred over the bog surface very rapidly (*cf.* Svesson, 1988), with a mixing of insect communities. The speed of beetle species' response to changing acidity is not known, but it is possible that time lags may operate, resulting in the co-existence of acid and non-acid species for some time (Jordan, 1995; Brayshay and Jordan, *in press*). Foster (1995) records that acid-loving aquatic species continue breeding on sites which have been enriched by liming. However, since his example is not a long-term study it is unclear how long such a situation would persist.

7.7 Period *c.* 1,000 cal BC to *c.* 700 cal AD

This period is represented by fossil insect assemblages in the upper part of the LIND B sequence and by assemblage zone 3 at HAT 4. The assemblage from LIND B contains many specialist species typical of ombrotrophic raised mire, but with a strong wet *Calluna* heath element. The assemblage from HAT 4 contains a large proportion of ombrotrophic-indicating species, including some raised mire specialists. Heath was also an important habitat. *Alnus* appears to have persisted in the area when most of the other tree taxa were no longer represented within the insect record, suggesting it had either had out-competed other trees (e.g. *Pinus*, *cf.* Chambers and Elliott, 1989) or that conditions, although wet, were still good enough for it to continue growing, perhaps due to disturbances. Chambers and Elliott (1989) suggest that *Alnus* tends to expand with site disturbance, including burning. The sample where this occurs (14) contained charred material, which could indicate localised burning.

The record from the top part of the sequence at HAT 4 appears to have been truncated, sometime before 560-680 cal AD (top of the profile, 1405 ± 45 BP, SRR-6120). The period between 1220-920 cal BC (2870 ± 40 BP, SRR-6121) and 560-680 cal AD (1405 ± 45 BP, SRR-6120) (i.e. maximum of 1780 years and minimum of 1,600 years) is represented by 25 cm of peat deposition. It seems unlikely that such a small deposit could represent such a long period, even if there had been a hiatus in peat deposition. In some instances, autocompaction can reduce thickness, especially with unhumified peats (Aaby and Tauber, 1975; Smith, 1985). However, it seems unlikely that autocompaction can account for such low rates of peat deposition. Indeed, at HAT 2, Smith recorded 70 cm of deposit for the period between 910-800 cal BC (2675 ± 70 BP, CAR-256) and 250-410 cal AD (1700 ± 65 BP, CAR-263), a period which corresponds to just under that represented by the period under discussion. There is strong evidence to suggest that peat accumulation rates and degree of humification are inversely proportional (Aaby and Tauber, 1975; Barber, 1981, 1985), although this relationship is not always true (*cf.* Smith, *in press*, 68). The peat in this part of the profile is unhumified, suggesting rapid deposition. It seems unlikely that 25 cm of peat could represent the period under discussion. The most likely explanation is that an unknown amount of peat has been lost, perhaps in the region of 40-60 cm, representing between 500-1000 years or more of peat deposition. The most likely explanation for this loss would appear to be peat cutting, sometime before 560-680 cal BC.

Palynologically, this period covers pollen zones HAT 1/C, D, E and F and HAT 2/D, E, F, G (Smith, 1985). Since a section of the HAT 4 sequence appears truncated, much of the following account cannot be correlated with the fossil insect evidence. Smith (1985) initially recorded an increase in some arboreal taxa, which he thought reflected regeneration in areas of abandoned cleared forest, possibly in the vicinity of Lindholme Island. Clearance herbs show increasing values, suggesting the continuation of pastoral farming in the early Iron Age and continued forest clearance on the higher ground surrounding the Moors. During zones HAT1/D and HAT2/E, (Iron age), continued opening of the forest canopy appears to have occurred, with indicators of pastoral and agricultural activities. Fluctuations in *Calluna* pollen are reflected in the insect evidence from the top part of LIND B. During the pre-Roman Iron age and Romano-British period (zone HAT1/E and HAT2/F) there appears to have been a marked increase in agricultural activity, with arboreal taxa decreasing and values for herb pollen increasing dramatically. *Calluna* values rose at this level, perhaps reflecting the importance of this plant upon the mire. Smith (*op. cit.*) suggests the landscape had an open appearance, although Lindholme Island may have remained forested. At the end of the Romano-British period and in the early medieval period (zone HAT1/F and HAT2/G) there appear to have been signs of a reduction in agricultural activity, with subsequent woodland regeneration.

Part of this latter record probably correlates with the top part of HAT 4. Insect evidence suggests open conditions, with *Calluna* forming an important vegetational component. There are indications of a possible return to mesotrophic and drier conditions. The top part of the profile contained frequent remains of charred peat and *Calluna*, suggesting *in situ* burning. This could explain the presence of some mesotrophic indicator species, as more nutrients would have been released by burning. Indicators of an increase in eutrophic influences have often been noted at the top of profiles (e.g. Wybunbury Moss, Cheshire), a feature generally attributed to anthropogenic influence directly or indirectly increasing the nutrient supply to mire surfaces (Green and Pearson, 1977). *Pinus* woodland may have been present during this period. This is indicated by the re-occurrence of several pinewood/heath species, raising the possibility that *Pinus* woodland had persisted in this area throughout the period represented by the sequence.

7.8 Discussion

7.8.1 The nature of the fossil forest

Decaying wood hosts a great variety of insects, particularly beetles (Palm, 1951; 1959) and natural forests have immense amounts of dead wood standing and lying beneath the forest canopy (Elton, 1966). Dead and dying trees or those beginning to rot provide an unrivalled series of micro-habitats for the fungal and animal communities of rotting wood. Deep twig and leaf litter on the ground contribute to the multiple patterns of the woodland floor (Elton, 1966). The fossil insect record from Hatfield Moors provides evidence for such a mature, largely undisturbed forest preserved within the basal deposits of the mire. The woodland fauna occurring between 4000 and 3000 years ago contained a range of species that are now very rare or extinct within Britain. Today, there are no comparable sites in Britain and the assemblage would be considered highly exceptional in Europe.

Many of the species are associated with very mature trees, suggesting that little dead wood was removed from the site by humans and that trees were allowed to reach full maturity. The data suggest that *Pinus* was the most important component within this forest, although *Quercus* and *Betula* were also present. Areas of *Pinus* woodland existed on the margins of the developing mire for some considerable time, possibly up to the present day on Hatfield, and undisturbed woodland faunas persisted in the lagg fen area up to *c.* 1500 years after peat initiation. *Pinus* trees appear to continue growing on the sand dunes in some areas and perhaps occasionally expanding during periods of mire dryness. Palynological evidence (Smith, 1985) suggests that Lindholme Island remained wooded for long periods of time. Thus, most of the palaeoecological evidence suggests that the "fossil forest" continued to regenerate in some form or another for a considerable period. Historical evidence suggests that *Pinus sylvestris* was a major component in the decaying forests of Hatfield Chase. Peck (1815) alludes to historical evidence from *c.* 1100 regarding the "Great Old Decaying Forest" of Hatfield Chase. He was possibly referring to the Mowbray Award (Limbert, *pers. comm.*, 1998), written in 1360, although the location of these papers is currently unknown. What is certain is that parts of the Moors supported considerable numbers of this tree as recently as the end of the sixteenth century (De la Pryme, 1701, 1702). The trees that still grow on the Moors are considered descendants of native *Pinus* (Skidmore, *in press*; Eversham, 1997b) and presumably of the fossil forest (Eversham and Lynes, 1983). It is perhaps no surprise that Hatfield Moors contains an extensive woodland invertebrate fauna (Skidmore, *in press*), illustrating a continuity and stability of woodland habitats stretching back several thousand years. However, this fauna is considerably impoverished of its saproxylic elements, and highlights the extent and impact of environmental change within forest environments over the last 3,000 years. The saproxylic fauna associated with major boughs and trunks of large, long-lived trees such as *Quercus* and *Fagus* have been most adversely affected by such habitat loss and change (Speight, 1989). However, the fossil record from Hatfield Moors suggests that the saproxylic fauna associated with *Pinus* has also been subjected to considerable habitat loss and change.

7.8.2 Fossil insect evidence for forest fires

Field survey and the insect samples highlighted the presence of abundant charcoal at Tyrham Hall Quarry and at Kilham West, suggesting that much of the fossil woodland had been burnt. Similar observations have been made regarding the fossil forest at the base of Thorne Moors (Whitehouse, 1993; 1997; Dinnin, 1994; Boswijk, 1998). At Tyrham, both the *Quercus* and *Pinus* samples contained abundant charcoal, although whilst many of the *Pinus* from Tyrham were charred, the *Quercus* was not. The period separating the *Quercus*' death and the *Pinus* woodland appears to have been about 500 years. It might be tempting to hypothesise that at least two separate fires had occurred.

During periods of seasonal dryness peat fires can occur easily (*cf.* Roworth and Roworth, 1995). The charred trees at Tyrham were covered by 2 metres of peat, which excludes charring as a result of recent peat fires. However, peat fires can also burn material once it is buried in the peat body (e.g. Reid, 1895). Fires can generate sufficiently high temperatures to ignite the surface horizons, which can smoulder for weeks, destroying from a few centimetres to several metres of organic material (Legg *et al.*, 1992) and during recent times, peat deposits have been known to occasionally burn to the mineral ground (Wein and MacLein, 1983). Although there is no evident stratigraphic evidence that could indicate burning within the peat body itself, this possibility cannot be entirely excluded.

It is worth discussing the fossil insect evidence associated with the "burnt" woodland to examine this issue. Certain species of Coleoptera are attracted to fires or immediately after the flames have subsided (Champion, 1909; Evans, 1971; Hunter, 1977; Lundberg, 1984; Wikars, 1992). Pyrophilous species appear to develop almost exclusively in burned areas, usually 1-5 years after a burn (Holliday, 1992). Much attention has centred on the buprestid *Melanophila acuminata* (Deg.) although other members of the family also appear to be pyrophilous. This is the most studied fire-adapted species (Collin, 1918; Linsley, 1943; Benoit, 1965; Evans, 1966; Evans and Kuster, 1980), and can arrive at a fire site in great swarms, within 24 hours (Barratt, *pers. comm*) (Plate 8.1). Many of these fire-adapted species live on dead or dying wood, which is generally abundant after a woodland fire (Wikars, 1992). Re-exposed and burnt fossil wood will not attract pyrophilous xylophages as the associated fungal communities will be different and a different range of species is attracted (P. Buckland, *pers. comm,* 1998).

Pyrophilous species within fossil deposits are likely to indicate burning of *exposed* wood, rather than burned *buried* wood within the peat body, although a number of *caveats* have to be considered. The literature specifically on pyrophilous insects is limited (e.g. Evans, 1971; Lundberg, 1984; Ahlund and Lindhe, 1992; Wikars, 1992; Muona and Rutanen, 1994), and whilst a certain core of species is recognised as being attracted to fire, there are others that are unclear regarding their pyrophilous status (e.g. *Zimioma grossum*). There are also some species that are strongly attracted to fires without being fire dependant, such as the Fennoscandian cerambycid *Monochamus sutor* (Wikars, 1992). In common with many other saproxylic invertebrates, the abundance of dead wood is likely to be a important determining factor in their presence. In addition, the importance of repeated disturbances for many saproxylics (e.g. fire; wind-blow of trees) may be under-estimated (Ahlund and Lindhe, 1992).

A range of other species is attracted to a burn site. For instance, wood-boring beetles will be attracted to fires, with the greatest attack occurring on trees that are most heavily fire-damaged (Danks and Foottit, 1989). After fire, there is a rapid growth of bacteria and fungi. Beetles of the family Lathridiidae, which feed on these fungi, can reach densities of over 100 individuals per square metre a few weeks after a fire (Koponen, 1989; Wikars, 1992). A concentration of Lathridiidae is evident at the location of a burned *Pinus* on Thorne Moors (Whitehouse, 1993) and could indicate *in situ* burning. Some Carabidae are also often present at the scene of forest fires. Members of the genera *Agonum* and *Pterostichus* are typically found in burnt-over forest areas in Scandinavia (Evans, 1966), although they are also frequent in peatlands.

Thus, the co-occurrence of a range of pyrophilous and other species could indicate whether charcoal represents *in situ* fire in the *Quercus* and *Pinus* woodland or whether burning occurred at a later date. Only one species considered pyrophilous appeared in the *Quercus* sample, the cucujid *Bitoma crenata*. This is a beetle which Lundberg (1984) suggests is attracted to burnt woodland, although this may be questionable. Several other pyrophilous species were recovered from the *Pinus* samples, such as the ground beetle *Dromius quadrinotatus* and the scolytid *Dryocoetinus villosus*. The former species has been found beneath fire-damaged *Pinus* (Champion, 1909) and Palm (1959) regards it as a fire species. Whitehouse (1993) recovered this species associated with charred *Pinus* on Thorne Moors. Although the scolytid *D. villosus* is usually found on *Quercus* and occasionally other deciduous tree species (Palm, 1959), it can also be found on large stumps and older trees damaged by fire (Palm, 1959). However, a review of the literature indicates that neither species is exclusively pyrophilous (e.g. Alexander, 1994), although this may be due to the lack of studies focusing on fire habitats. The evidence regarding whether these species were attracted to a burning forest is thus not conclusive, although it does provide some support for the idea that the wood was exposed when burnt.

Other evidence can be utilised to examine the issue of *in situ* fire. Boswijk (1998) notes that the end phases of the *Pinus* woodland at Tyrham were represented by many trees that were coming under increasing stress, probably brought about by wetter conditions. Trees were living for shorter periods of time; left naturally, *Pinus sylvestris* can grow for up to 500-600 years (Zackrisson, 1977). The woodland at Tyrham was dying, an interpretation that is very strongly corroborated by the insect evidence. Not only were trees dying, but quantities of rotting and dead wood were providing ample food for many saproxylic invertebrates. Boswijk (*ibid.*) noted no fire scars in any of the *Pinus* material, which means that none of the sampled trees had survived previous fires. However, *Pinus* is one of the most fire resistant trees and can be repeatedly exposed to fire without being killed (Uggla, 1958, Engelmark, 1987; Boswijk, 1998). Old *Pinus* stumps in Sweden can show fire scars from at least seven fires (Ahlund and Lindhe, 1992). Whilst relatively small trees will be killed, a high portion of the largest height class trees (20-26 m.) will survive a fire (Sepponen, 1989). Thus, fire tolerance of a tree increases with diameter and bark thickness (Sirén, 1973). The trees at Tyrham were reasonably large and long-lived, but there were no fire scars or signs of recovery (Boswijk, 1998). This strongly suggests that the *Pinus* woodland was dying or dead at the time of the fire; the lack of bark on many *Pinus* samples and the depth of charring support the idea that the trees were either moribund or dead (Boswijk, 1998). During survey work, it was noted that many charred trees appeared to have been partially burnt, as if lying on the ground: some of the fallen dead trees may have been protected, possibly by a peaty humus layer, mats of *Sphagnum* and lichen, or by fallen trees.

The limited pyrophilous insect evidence suggests that the trees were not buried within the peat at the time of burning. Circumstantial evidence of the extensive and consistent nature of the observed charring at Tyrham and Kilham West suggests the basal wood was exposed during burning. A ready availability of combustible fuel, together with flammable resins from the *Pinus*, coupled with a period of low rainfall, low humidity, high temperatures and high winds (Wagner, 1983) could have facilitated the ignition of the woodland in these areas. The high frequency of *Calluna vulgaris* would also have served to facilitate surface fires (*cf.* Engelmark, 1987).

In contrast, had charring occurred from a peat fire, stratigraphic evidence of charcoal through exposed profiles might be expected. There would also have been a much greater unevenness of charring, with the fire penetrating to the basal wood deposits only in certain areas. This, however, does not appear to have been the case. Whilst not all tree trunks were burned, the charring consistently covered extensive areas.

Boswijk (1998) records that the earliest tree noted with charring died in 2703 BC; the last charred tree in the chronology died in 2590 BC. As Boswijk notes, this might indicate two separate fires. However, dating the *charred* trees does not date the *fire* event, which could have occurred sometime after 2590 BC. Boswijk (*ibid.*) found possible circumstantial evidence of fire as narrowed tree rings between 2570 and 2575 BC. However, this could have represented a phase of persistently high ground water levels or flooding, contributing to the death of the trees. It is tempting to suggest that the dying woodlands at Tyrham and Kilham West burnt sometime *after* 2590 BC.

The *Quercus*, living 500 years previously, may have been still exposed or thinly covered by peat and may have burnt at the same time. Charcoal was noted from the sample, rather than on the wood itself, which could have been incorporated later. However, it is impossible to discount the possibility of a separate previous fire episode. Most of the literature suggests that *Quercus* cannot be burnt (unless deliberately) (e.g. Rackham, 1986), although areas of burnt *Quercus* on Thorne Moors suggests this view may be rather simplistic (Whitehouse, 1993; Dinnin, 1994; Boswijk, 1998).

Charred *Pinus* trees were also noted on the sand dunes and the margins of Lindholme Island (Chapter 4). These trees remain undated and appear to have been growing in increasingly stressed conditions, indicated by their shallow-rooting system and spindly and weak structure. These trees were living under very different conditions to those at Tyrham and Kilham West. The dunes would have been elevated above the developing mire. Stratigraphic evidence indicates that the trees continued living on the dunes whilst mire development was relatively well advanced, as long as peat and water levels permitted, or perhaps the *Pinus* re-colonised during periods of mire dryness. This evidence that the dune trees are more recent that those from Tyrham and Kilham.

Smith (1985) noted a charcoal layer at HAT 1 and HAT 2 dated to 2040-1780 cal BC (3570 ± 70, CAR-169) and 2200-1970 cal BC (3685 ± 65, CAR-256, 4 cm below charcoal layer), respectively. Since these dates are significantly later than the burnt trees from Tyrham, the charcoal deposits may provide evidence for at least one other fire episode on Hatfield Moors during the prehistoric period. The charred *Calluna* noted at the base of LIND A may date to this period. The charred dune trees could also have been burned during the same episode, although such a connection is speculative.

7.8.3 Mire genesis and development

The fossil insect record indicates that ombrotrophic conditions spread very rapidly across Hatfield Moors (see Table 7.1). There are few indications for eutrophic fen peat development, except at HAT 4, which probably represented lagg fen on the edge of the developing mire. Most of the entomofaunal evidence suggests that mesotrophic mire developed immediately above the nutrient poor sands and that ombrotrophic peats developed rapidly above these basal deposits. The processes which contributed to wetland development in the Humberhead Levels are discussed elsewhere (see Chapter 11).

The environmental data represented by the single Tyrham *Quercus* and its rot hole (3618-3418 BC) probably represent pre-peat landscape conditions, suggesting *Quercus-Betula*-dominated fen woodland. Peat probably did not start developing during this early period as more of this woodland would have survived and the "missing" 500 years between the *Quercus* and *Pinus* woodland would have been represented within the palaeoenvironmental archive. However, it is possible that the preservation of the tree represents a temporary rise in water levels, perhaps in response to rising water levels elsewhere. The insect evidence indicates permanent pools with rich fen littoral vegetation. This vegetation could be contemporaneous with the period of the *Quercus*' death, or more likely, to the period immediately afterwards, suggesting increasingly wet and mesotrophic conditions. These factors would have favoured the transition to *Pinus* woodland/heath with *Betula* and *Alnus* fen vegetation.

There may have been localised peat development on other areas of Hatfield Moors, perhaps on the eastern side or off the present margins, to the north and east. There is one radiocarbon date from the eastern side of the Moors (HAT 2, 3090-2890 cal BC [4335 ± 75 BP, CAR-254]), which is slightly earlier than other dates from the western side, but may not be as early as that from the most northerly site dated (HAT 3, 3350-2930 cal BC [4480 ± 45 BP, SRR-6119]). A.G. Smith (1958a) noted that the south-eastern sector of Hatfield contained the deepest peat deposits, although this may not be significant regarding peat initiation. In the same area, Dinnin (1997c) draws attention to topographic low points in the areas of New Moor south and New Porters Drain.

Unfortunately, there is insufficient data to test the possibility of localised peat development in this area. The rivers Idle and Torne both used to flow very close to the eastern, south-east and south side respectively of Hatfield Moors. Figure 7.4, which shows the 1853 map of Hatfield Moors, illustrates very clearly the proximity of the eastern and southern side of the mire to the surrounding rivers. On the south-eastern side, the rivers were just a few hundred metres away from the Moors' margins. The map also illustrates that Hatfield was much more extensive than the present margins would appear to indicate, with larger areas to the east and north.

The range of radiocarbon dates across the site suggest that mire development occurred more or less simultaneously, centering around 3000 cal BC, as the basal peat initiation dates shown in Figure 7.5 and Table 6.1 illustrate. The basal dates from Smith's (1985) pollen sites HAT 1 and HAT 2 date peat initiation in these areas to around 2900-2620 cal BC (4180 ± 70 BP, CAR-168) and 3090-2890 cal BC (4335 ± 75 BP, CAR-254) respectively. At the fossil insect site of HAT 3 peat initiation began around 3350-2930 cal BC (4480 ± 45 BP, SRR-6119) and at least by 2900-2350 cal BC (3990 ± 60, BETA-91800) at Lindholme B. It is worth noting that these dates correlate closely with rheotrophic fen peat development on Rawcliffe Moors (Thorne Moors) (Smith, 1985), suggesting similar causal links in the Moors' development.

This initial phase of peat development overlapped with the growth of the *Pinus* woodland (2921-2445 BC), at least at Tyrham Hall Quarry and Kilham West. The fact that trees continued growing in the area 500 years after peat initiation in other areas of the Moors led Boswijk (1998) to suggest that peat inception at Tyrham lagged development in other areas by about 500 years. However, the preservation of trees through the *whole* dendrochronological period and the presence of some obligate ombrotrophic beetle species (e.g. *Curimopsis nigrita*) as well as eutrophic fen species, suggests that mesotrophic *Pinus* woodland continued growing in the area during the early stages of peat development. Peat had probably started accumulating at the beginning of the *Pinus* chronology (i.e. at least by 2921 BC). The insect evidence suggests earlier mesotrophic conditions, but that increasingly ombrotrophic and wet conditions developed. The demise of the woodland was probably intimately linked to the onset of these conditions. Forest deterioration can occur when *Sphagnum* mosses saturate the forest floor, which cause trees to grow less rapidly because of lack of aeration to the roots (Klinger *et al.*, 1990), as well as nutrient depletion (Heilman, 1966). Paludification of coniferous woodland has been noted at numerous sites (e.g. Bridge *et al.*, 1990; Gear and Huntley, 1991; Hulme, 1994). The speed at which this transition occurred is evident in the overall good preservation of the Tyrham trees, suggesting that they were quickly enveloped within the growing mire. The presence of a well-developed *Calluna* heath may have been an essential element in this very rapid transition. A factor that can induce rapid growth of *Sphagnum* appears to be the presence of *Calluna*, since there appears to be higher productivity of both *Calluna* and *Sphagnum* when the two grow together, as the latter appears to use the former as "scaffolding" upon which to grow (Barber, 1981).

Within a couple of hundred years of the death of the Tyrham woodland, Smith (1985) notes a marked *Pinus* pollen decline, dated sometime between 2040-1780 cal BC (for HAT 1) and 2200-1970 cal BC (for HAT 2). This decline probably reflects the demise of *Pinus* woodland that had been growing on the mire and its margins. The fire may have contributed to the *Pinus* decline and the final death of the woodland, although it was already reaching the end of its life-span. It may have had the effect of killing off any remaining trees in the area and ensuring that wetter and more acid conditions prevailed by altering the hydrological balance of the site.

The radiocarbon dates provide a possible hint of a marginal time-lag in peat initiation in some areas (e.g. between dates from HAT 3 and HAT 1, see Figure 7.5), perhaps in the most lower-lying areas, such as within the "hollows" between the sand dunes. Many of the dunes protrude through the peat today as a result of peat cutting and some were a visible topographic feature at the beginning of the 19th century, "*In the middle of this vast portion of boggy earth the summits of former hills rear their boney heads, scarcely overtopping the surrounding plain*" (Wainwright, 1818, 299). The dunes are up to 4 metres in depth (Gaunt, 1994) and although this provides no indication of the depth of the "hollows", it is unlikely that the radiocarbon dates indicate peat initiation within the "hollows" since this would entail sampling a very specific location. If peat development began within these low points, it may have formed within *many* of the hollows (essentially poly-focally), perhaps more or less simultaneously, growing outwards into a coalesced whole. Alternatively, peat may have developed from one point, moving rapidly outwards. However, the nature of the undulating substrate, which would have been a topographic barrier to a "peat front", and closely clustered initiation dates would suggest more-or-less simultaneous poly-focal peat development. Theoretical models of mire development appear to be of limited utility when studying actual situations prevalent in nature, where bog development appears to be variable, essentially idiosyncratic and closely related to the immediate physical environment such as topography and substrate (Korhola, 1992; Glaser *et al.*, 1997). This is nowhere more evident than at Hatfield Moors.

The fact that *Pinus* and *Betula* woodland continued growing on the top of the sand dunes whilst peat growth was occurring on the lower lying areas, before being subsumed by the peat complex at a later date, would support the hypothesis of poly-focal development. The stratigraphic evidence does not indicate whether these trees continued growing upon these topographic features or whether *Pinus* grew on the sand dunes during episodes of greater dryness. There is at least one instance where two different phases of tree growth were noted in exposed sections (e.g. Kilham East), with *c.* 1.20-1.30 cm. of peat separating the different phases. Tree growth may have become possible on some sand dunes during periods of mire dryness. This may have been in response to the death of bryophytes after a long period of drought or could reflect small-scale edaphic changes in surface hydrology on the site. Klinger *et al.*, (1990, 78) observed that on two bogs in Alaska, tree growth became possible periodically, where *"small stunted trees commonly grow on raised micro-sites in bogs"*, a similar description of the trees observed by the author on Hatfield Moors. Smith's (1985) evidence for recurrence phases indicates different periods when trees could have seeded onto the mire surface. There is no evidence to suggest these trees formed into forest communities, but appear to have been temporary expansions onto the mire surface.

7.8.4 The importance of the heathland component within assemblages.

One of the most striking aspects of the Hatfield Moors insect assemblages relates to the evident importance of heath-loving species and the mixture of xerophilous and hydrophilous communities. Heathland has been an important ecological habitat for the last 4000 years on Hatfield Moors, with *Pinus sylvestris* and wet *Calluna-Eriphorum* mire/heath as major components within the wetland landscape. This aspect has been highlighted by Peter Skidmore's (1997, *in press*) recent invertebrate survey work and he questions whether this is a relatively recent development. The fossil insect work provides the long-term ecological perspective required to answer this question.

Historical evidence from the last century describes Hatfield as a "*heather-clad expanse, ... a wild primeval bog...*" (Anon., 1888, 85); the source also refers to Hatfield as a "*heath and morass*"(p.87). Hatfield is recorded as *Haifeld* in the Domesday book, from the Old English *haeth* and *feld* (Morris, 1982, 81), probably referring to the areas of open heath. Figure 7.4 (O.S. map for Hatfield, 1853) indicates a number of footpaths traversing Hatfield, which suggests that the Moor was at least seasonally dry. In contrast, areas of Thorne Moors could not crossed up to the 1960's and 70's (Limbert, *pers.comm.*), even during summer. Figure 7.4 illustrates that Hatfield was surrounded by wetlands, carrs and heaths. Areas of drier heath, with vestiges of *Pinus sylvestris* woodland, occurred as isolated patches near Poor Piece and on the western side of the Moors. Other areas occurred within a few kilometres of the present western margins of the Moors, on West Moor and Hatfield Lings (Eversham and Lynes, 1983). These areas once supported an invertebrate fauna which was as distinctive and significant as that of Lindholme Island (Eversham, 1997b). Hatfield Moors, therefore, should be seen as part of a complex wetland landscape comprising raised mires and wet/dry heathlands.

7.8.5 Peat micro-topography

The assemblages provide some indication of the peat micro-topography across Hatfield Moors. Numerous peat pools existed on Hatfield Moors, shown by the abundant aquatic fauna. Some pools may have been sizeable and may have been more-or-less permanent features of the mire. Areas probably exhibited the characteristic hummock/hollow structure associated with raised mires, although those locations dominated by *Calluna-Eriophorum* may have been less subject to such patterns (Rodwell, 1991). In the last century, the wet and inhospitable nature of the Moors deterred many visitors. In 1839, Stonehouse remarked (in Eversham and Lynes, 1983, 27) that when he crossed from near Sandtoft to Lindholme during the dry weather of August 1836 he found that it *"required very great care in stepping from turf to turf..".* In 1878 a foray of the Goole Scientific Society crossed Hatfield Moors and commented that the flora of the Moors *"closely resembled that of Thorne Waste"* (Evesham and Lynes, 1983), including many moorland species such as *Erica tetralix*, *Vaccinium oxycoccus*, *Andromeda polifolia*, *Myrica gale*, *Eriophorum vaginatum* and *Rhynchospora alba*. An account in 1888 (Anon.) suggests that bog pools were still treacherous on the Moors. A glance at the 1853 map (Figure 7.4), however, indicates that any large bog pools had disappeared, except for one on the south side of Lindholme. The rather irregular nature of the pool suggests it was at least partially artificial and may have been a peat cutting or have served as a duck decoy (*cf.* Limbert, 1998), but was perhaps the vestige of a more extensive pool system. By the 1950's, when a new set of maps were drawn up, the pool had disappeared. From 1887 onwards, historical accounts suggest that Hatfield became progressively drier as a result of drainage activities and subsequent peat cutting (Eversham and Lynes, 1983).

7.8.6 Anthropogenic signals within the faunas

The paucity of archaeological evidence identified during field survey was surprising, particularly as prior to peat formation the area would have been freer-draining. The Moors *should* have been a prime location for human activity, particularly on the top of the sand dunes, but this was not detected. Sandy levées and exposures were often the focus of Mesolithic and Neolithic activity in the Humberhead Levels (e.g Wroot-1 to 4 and Crowle-2 of Head *et al.*, 1997b), but the lack of evidence may be due to poor archaeological visibility.

The insect samples contained virtually no indication of human activities on Hatfield Moors and are typical of undisturbed forest and mire insect faunas. There is also little indication of animal activity. Several species of dung beetle were present within deposits, but were present in such low quantities that they could have been incorporated adventitiously. Alternatively, the beetles may have been associated with the dung of large herbivores roaming the Moors, such as red deer, which are historically known to have lived on the Moor (De la Pryme, 1671-1700) and continue presently (*cf.* Howes, 1997; 1998). Such herbivores may have found the Moors attractive for grazing, particularly during drier periods of the year. People may have periodically grazed animals on the Moors, but this has left no clear palaeoentomological record.

The presence of people using and moving through this landscape is documented by Smith's (1985) and others' (Smith, 1958a; Turner, 1962) palynological work and, there is ample archaeological evidence from the surrounding areas (Chapter 2). Much of the surrounding landscape appears to have been extensively cleared for agriculture by the Iron Age and perhaps earlier (*cf.* Riley, 1980, 1988). It is difficult to believe that the area was not utilised, even if only in a minimal way, by humans.

7.8.6.1 Woodland management

The first possible indication of human activity relates to the burnt woodland at the base of Hatfield Moors. Different researchers, referring to Thorne Moors, have suggested this was the result of deliberate burning of the woodland by prehistoric people (*cf.* Buckland and Kenward, 1973; Smith, 1985), perhaps as part of woodland management, clearance or even to encourage animals to the area (*cf.* Mellars, 1976). However, there are many problems associated with this interpretation (see Chapter 11).

7.8.6.2 Heath management

There is a strong possibility that Hatfield Moors was used for animal grazing, if not all year round, at least seasonally. Chambers (1996, 174) discusses the past use of mires for grazing and how they were often burnt to maintain *Calluna* cover as part of grazing practice. As a grazing plant, *Calluna* must be kept short with the minimum amount of wood growth, which is achieved through an optimal amount of grazing and by burning the heath (Kaland, 1986). Burning also improves the quality of the browse. Some studies have indicated that there is a strong correlation between fire history and local

Calluna-heath expansions and their maintenance (*cf.* Odgaard, 1988, 1992; Bunting, 1996). Given the abundant evidence for *Calluna* heath on Hatfield Moors and the frequent occurrence of charcoal in the upper peats from HAT 4, this may indicate deliberate burning of the mire to produce grazing. The Inclesmoor map (Figure 1.4, see section 1.7) illustrates the former importance of the raised mire resource for peat cutting, but it may also have been important grazing. It is possible, of course, that the occurrence of charcoal in the upper peat deposits may be the result of natural mire fire on the Moors. With the increase in nutrient status of peat following such fires, *Calluna* seedlings would have shown renewed vigour (Legg *et al.*, 1992), and this may have resulted in an increase in browsing animals attracted to the area, or the increased use of the mire by people grazing their animals.

7.8.6.3 Peat cutting

It has been previously argued that the sequence at HAT 4 may have been truncated by peat cutting, sometime before 560-680 cal AD (section 7.7). The most obvious time when such an event could have occurred would have been during the Roman period. Peat cutting in this area is documented from at least the early medieval period (De la Pryme, 1698; Miller, 1804; Eversham, 1991). However, there is no reason to believe that peat cutting was not taking place prior to this. Knowles (1990, 370) suggests that the proximity of the Cowick potteries to the Moors may have been because kilns were fired with peat as well as coal. It is not inconceivable that the Roman potteries located within the Levels (Buckland *et al.*, 1980; Buckland *et al.*, *in press*) made use of peat turves from these Moors for kiln firing. Much of the evidence supports the idea that the Levels were substantially cleared by the Roman period (*cf.* Buckland and Sadler, 1985), so alternative sources of fuel may have had to be utilised. The extensive river system of the Levels could have been used to transport goods such as pottery as well as peat.

There is environmental evidence from York Roman which suggests that peat was being utilised during this period (Hall *et al.*, 1980). A well from Skeldergate contained the remains of large quantities of fibrous peat, including blocks of peat, largely consisting of *Eriophorum vaginatum*, *Sphagnum* and *Calluna* as well as insect remains characteristic of acid peatland and drier heathland habitats. The precise source of this peat could not be determined, but it indicates that peat was transported to York, probably for fuel purposes (Hall *et al.*, 1980).

CHAPTER VIII: PALAEOENTOMOLOGICAL RESULTS FROM THORNE MOORS

8.1 Introduction

This chapter presents and discusses the results from a site examined along Blackwater Dike, Goole Moors (location D on Map 4.3). The succession was chosen to study the transition from *Quercus*- to *Pinus*-dominated woodland on Goole Moors. The lower seven samples were analysed in order to examine this early period of mire development. Previous fossil insect work had already examined the successive deposits (*cf.* Buckland 1979; Roper, 1993, 1996; Whitehouse, 1993, 1997a). The results from this single study site are discussed within the context of this and other previous palaeoecological work (Smith, 1985; Boswijk's, 1998). Although Smith's pollen site GLM 2 is located *c.* 100 metres from the sampling site (Figure 4.3), he did not sample the basal deposits from this site. GLM 1, *c.* 500 metres from the site is the nearest complete pollen sequence. Table 5.3 presents all relevant dates.

8.2 Blackwater Dike, Goole Moors, *Quercus/Pinus* sequence.

8.2.1 Introduction

Seven fossil insect assemblages were examined, representing 685 MNI, across at least 153 species, from 30 families of Coleoptera. Figure 4.10 shows the stratigraphic relationships between samples. Table 8.1 lists the insect fossils recovered. Appendix C provides additional information on the samples processed and identification problems are discussed in Appendix D.

8.2.2 Age of the deposit

The *Quercus* at the base of the sequence is dendrochronologically dated to 3444-3242 BC (TM 01 chronology, 3777-3017 BC) (Boswijk, 1998). Whilst this does not necessarily date peat initiation in this area, it provides some indication of when the *Quercus* tree was growing. The spatially closest date for peat initiation is from Smith's GLM1 site, dated to 3350-3100 cal BC (4515 ± 70 BP, CAR-232). It seems reasonable to assume peat initiation in this area sometime *c.* 3400-3100 cal BC.

Although the *Pinus* remains at Blackwater Dike have not been dendrochronologically dated, Boswijk (1998) studied the different phases of the *Pinus* woodland on Goole Moors, which she dated to the period between 2921-1489 BC. This was the first set of *Pinus* dendrochronological chronologies from mainland Britain to be dated, providing the first ever link between *Pinus* from different raised mire sites in England (Chambers *et al.*, 1997), as well as creating the first long-distance cross-match between *Pinus* chronologies from England and Northern Ireland (Boswijk, 1998). This general chronological framework provides some indication of the temporal span of the part of the succession examined. On Rawcliffe and western Goole Moors early *Pinus* were growing between *c.* 3358-3186 BC, including some just north of Blackwater Dike. The *Pinus* remains observed in the profile may have belonged to this chronology. However, since the remains stratigraphically superseded the *Quercus*, which died in 3242 BC, the *Pinus* growing on the site is likely to post-date this early flush of trees. The next period when the trees may have been growing is likely to have been contemporaneously with the first major *Pinus* woodland (2921-2445 BC) (Boswijk, 1998).

The samples therefore probably date from at least 3444 BC to sometime between 2921-2445 BC, covering the crucial transition period from *Quercus*-to *Pinus*-dominated woodland in this area. Although this broad chronology is offered for this section of the succession, no attempt is made to date the individual fossil insect zones.

8.2.3 Results

The samples contained a range of very well preserved insects (all samples except 20 scored 4 on the Preservation Index). Members of the families Carabidae, Dytiscidae, Staphylinidae, Scirtidae, Chrysomelidae, Scolytidae and Curculionidae dominate the faunal assemblage. Six non-British species were recovered, all of which have been found previously in fossil deposits, although not all from Thorne Moors. Charred material was noted from samples 17 (112-107 cm.) and 18 (117-112 cm.) only. Figure 8.1 illustrates the insect fossil diagram, together with faunal assemblage zones and dates. Table 8.2 shows the classification assigned to each species. To facilitate interpretation of the insect assemblage, the diagram is divided into 3 zones.

Insect zone 1 (127-120 cm, samples Bulk 3, 20 and 19) is rich in insect material, with a total of 213 MNI recovered, across a minimum of 88 taxa. Fossils from this zone originated from dark black, well-humified peat, containing wood remains and some *Phragmites*. The zone is characterised by a very good representation of faunal elements associated with mature, ancient deciduous woodland. Small numbers of rheotrophic fen species are represented. Hygrophilous and aquatic species increase through the period.

Insect zone 2 (120-109 cm, samples 18 and 17) contains a total of 286 MNI, across a minimum of 78 taxa. The samples originated from well-humified brushwood peat, with *Quercus* remains at its base and *Betula* and *Pinus* wood fragments becoming dominant higher up the profile. This zone is characterised by the continued presence of a strong forest community. There are increases within non-acid habitats, but acid-loving species remain insignificant. There are large increases in the aquatic communities.

Insect zone 3 (107-97 cm, samples 16 and 15) contains a reduced faunal assemblage (183 MNI, across 53 taxa). The insects originated from very well humified brushwood peat containing *Betula* and *Pinus*, which grades into *Sphagnum* peat with *Betula* fragments. There is an evident increase in species associated with *Pinus*-wood and a decline in those associated with deciduous-wood. There is also a marked decline in rheotrophic indicators and an increase in ombrotrophic-loving species.

8.2.4 Environmental reconstruction

8.2.4.1 Fossil insect zone 1 (samples Bulk 3, 20-19)

Bulk sample 3 and sample 20 have been examined together as they came from the same stratigraphic unit. This fossil insect zone is characterised by a diverse range of families, including Carabidae, Dytiscidae, Staphylinidae, Scolytidae and Curculionidae. A range of very rare and four non-British *Urwald* species is present.

8.2.4.1.1 The woodland community

During the earliest period (samples 20 and Bulk 3), *Pinus* appeared to have growing in the vicinity, indicated by its phytophagous Scolytids (e.g. *Tomicus piniperda* and the RDB 2 species, *Pityophthorus lichtensteini*). The two non-British pinicolous species *Cryptolestes corticinus* and *Rhyncolus sculpturatus* suggest the presence of undisturbed, abundant, dead-wood habitats. The weevil *Rhamphus pulicarius* is hosted by *Betula* and *Salix* spp. (Morris, 1993). There are no clear indications of *Quercus*, although this does not necessarily indicate its absence.

In contrast, the sample succeeding the basal samples (19) indicates that the most important aspect of the woodland community is represented by those species associated with deciduous *Quercus*-wood, such as the leaf-miner *Rhynchaenus quercus*. There is also a diverse range of rare *Urwaldrelikt* beetles. These include the non-British colydiid *Pycnomerus tenebrans* that live in red-rotted wood of old trees (Reitter, 1911), often in *Quercus*, although there are records from other deciduous trees (Horion, 1962). *Teredus cylindricus* is found under bark of old *Quercus* (on *Fagus* in mainland Europe) and appears to be a predator of the scolytid *Dryocoetinus villosus* and various anobiids (Donisthorpe, 1939; Palm, 1959; Horion, 1962; Shirt, 1987). The anobiid *Dorcatoma chrysomelina* lives in similar habitats (Alexander, 1994) and, together with *Grynobius planus*, may have been suitable prey. *Aderus oculatus* is repeatedly associated with

Dorcatoma as well as other species, emerging from red-rotted fungoid *Quercus* and *Tilia* (Horion, 1956; Palm, 1959; Bullock, 1993). It seems probable that these species were associated with the *Quercus*, rather than any other deciduous trees.

Other trees continued growing. *Rhynchaenus rusci* lives on *Betula* (Bullock, 1993). The scolytid *Dryocoetinus alni* is often associated with *Alnus glutinosa*, as well as *Corylus avellana* and *Fraxinus excelsior* (Bullock, 1993). *Pinus* also appears to have been growing in the vicinity, but perhaps in low numbers. Several *Pinus*-loving species were recovered from sample 19 (for example, *Pityophthorus pubescens* and *Rhyncolus ater*).

The presence of *Scolytus scolytus* is interesting since it is usually associated with *Ulmus*, although it has occasionally been recovered in other broad-leaved trees such as *Quercus* (Alexander, 1994). These beetles are notable for spreading Elm disease since they carry the spores of the pathogenic fungus *Cerastomella ulmi* (Elton, 1966, 285). Their possible role in the *Ulmus* decline in the early Neolithic (*c.* 4000 cal BC) has been the subject of several papers (Girling and Greig, 1985; Girling, 1988, 1989; Peglar, 1993).

The abundance of dead wood is particularly evident amongst the faunal assemblage from sample 19, with many species characteristic of decomposed wood and bark. These species are often predators of the primary colonisers of wood (for example bark beetles). Whilst many of the primary colonisers show a preference for specific tree taxa, to secondary colonisers it is often the state of wood decomposition rather than taxon that is of primary importance (Szujecki, 1987). Such species include *Rhizophagus ferrugineus*, *R. dispar* and *Cerylon histeroides*, all of which are found under the decayed bark of deciduous and coniferous trees (Reitter, 1911; Palm, 1951). The very rare non-British *Mycetina cruciata* is also present. This is an *Urwaldrelikt* species which prefers very moist wood in an advanced state of rot, and is particularly associated with bracket fungi (Palm, 1951). Although found in all types of wood, it appears to prefer conifers, at least within its northern distributional range (Horion, 1961).

8.2.4.1.2 The heath communities

During this early stage of mire development, areas supported *Calluna*-heath vegetation, indicated by the phytophagous *Calluna* feeder *Micrelus ericae*. The Notable B species *Acalles ptinoides* is often associated with *Calluna* and heaths and in the litter layer of deciduous woodland (Crowson, 1962; Hyman, 1992).

8.2.4.1.3 Non-acid wetland communities

This period is characterised by species mainly associated with rheotrophic fen conditions. Mildly basic environmental conditions are indicated by the presence of the reed beetle *Plateumaris sericea*. *Olophrum fuscum* is often found in *Phragmites*, *Carex* and *Juncus* detritus and under damp leaves and moss (Koch, 1989). The hygrophilous Carabidae *Pterostichus nigrita/rhaeticus*, *P. minor*, *P. diligens*, are all characteristic of fen woodland and bogs (Lindroth, 1945) and cannot tolerate very acid conditions.

8.2.4.1.4 Acid wetland communities

There are few characteristic species of truly acid raised mire conditions during this period, and *Plateumaris discolor* is absent. There are, however, some species commonly found in plant debris in *Sphagnum* bogs, such as *Ochthephilum fracticorne* and *Stenus kiesenwetteri* (Skidmore, 1970; Koch, 1989; Hyman, 1994).

8.2.4.1.5 The aquatic and hygrophilous communities

Amongst the aquatic species, there is a steady increase in this faunal component through the assemblage zone. In the basal samples, numbers of *Hydroporus* spp. are small. The larger Dytiscidae are represented by just one individual of *Agabus/Ilybius* sp. Areas of water were probably limited in extent, perhaps even just small seasonal pools. In contrast, sample 19 shows an increase in aquatic species, amongst both the small species as well as the larger water beetles which require larger pools of water. *Agabus affinis*, for instance, is often found in acid pools in *Sphagnum* (Friday, 1988). The large numbers of Scirtidae and many predatory staphylinid beetles would have inhabited damp plant litter and/or *Sphagnum* in and around these pools.

8.2.4.1.6 The decay community

Most of the species associated with this community would have been living amongst decaying plant debris and wood. *Dienerella separanda* is found in fresh bark of *Pinus* stumps, in fungoid heartwood (Koch, 1989), as well as in compost, hay and other rotting plant debris (Horion, 1962).

8.2.4.2 Fossil insect zone 2 (samples 18-17)

This insect zone is characterised by a range of families, including Carabidae, Dytiscidae, Hydrophilidae, Staphylinidae, Scirtidae, Scolytidae and Curculionidae. Three non-British *Urwald* species are present. Both samples contained charcoal.

8.2.4.2.1 The woodland community

The continued presence of *Pinus* in the area is suggested by the presence of the scolytids *Tomicus piniperda* and *Pityophthorus lichtensteini* from sample 17. Species that live off dead, rotting *Pinus*-wood are also present, such as *Rhyncolus ater* and the non-British *R. sculpturatus*. Indeed, the presence of fragments of this wood taxon in the samples indicates that *Pinus* was growing on the site. The continued importance of *Quercus* is suggested by its weevils *Rhynchaenus quercus* and *Acalles roboris*. *Dorcatoma chrysomelina* and *Abdera 4-fasciata* would have been attracted to any red-rotted *Quercus*-wood (Alexander, 1994), although both can be found on other deciduous trees (Hyman, 1992). *Rhynchaenus fagi* is usually associated with *Fagus sylvatica*, although occasionally it can also be found on *Quercus* (Bullock, 1993).

Rhamphus pulicarius is found on *Salix*, *Populus*, *Myrica* and *Betula* spp. (Morris, 1993), whereas *Rhynchaenus rusci* and the Notable B birch bark beetle *Scolytus ratzeburgi* indicate the presence of *Betula*. The latter attacks trees that are usually standing and weakened, often those damaged by fires, flooding or defoliated by Lepidoptera (Palm, 1951, 1959; Lundberg, 1984). The presence of charcoal and this beetle within both samples could suggest that *S. ratzeburgi* was attracted to fire-damaged *Betula*-wood. The non-British *Urwaldrelikt Bothrideres contractus* is a predator of Ipinidae and Anobiidae. It prefers rotting *Betula* and *Salix* spp. (Reitter, 1911), although it is also found in rotten conifers (Palm, 1959) and *Quercus* (Koch, 1989). The RDB 1 cerambycid *Oberea oculata* is usually found in fenland, often in *Salix* spp. (Shirt, 1987).

The abundance of dead wood is evident from the faunal assemblage from this period, which includes the non-British *Urwaldrelikt Mycetina cruciata* and the RDB 3 species *Colydium elongatum*, a predator in galleries of wood-boring insects (Palm, 1959) in decayed bark and rotting wood of deciduous and coniferous trees (Horion, 1962), but especially *Fagus* and *Quercus* (Päsche and Zachariassen, 1976). It is notable that this zone as well as sample 10 (zone 1) contains the highest number of species associated with rotting wood, after which there is an abrupt decline in dead-wood taxa.

8.2.4.2.2 The heath communities

This community represents a minor part of the assemblage. *Bradycellus ruficollis* is stenotopic of *Callunetum* (Lindroth, 1945). *Othius mymecophilus* is often found in old *Callunetum*, associated with old *Pinus*-wood (Richards, 1926), although it can also be found in tree litter, in *Sphagnum* and in rotting vegetation (Koch, 1989).

8.2.4.2.3 Non-acid wetland communities

There is an overall increase in this category. This is represented by increases amongst the hygrophilous ground beetles *Pterostichus diligens*, *P. nigrita/rhaeticus*, *P. minor* and *Agonum fuliginosum*. These beetles are commonly found together in moist shady places such as *Alnus* carr and fen woodlands (Lindroth, 1945, 1974), but mostly in minerotrophic to mesotrophic bogs (Koch, 1989). Mildly basic environmental conditions are indicated by the continued presence of the reed beetle *Plateumaris sericea.*

8.2.4.2.4 Acid wetland communities

This community still represents an insignificant faunal element, although there are indications that conditions were becoming more ombrotrophic. For instance, *Plateumaris discolor* appears for the first time in the sequence. This is a species associated with *Sphagnum* and *Eriophorum* (Stainforth, 1944) and typical of acid raised bogs (Koch, 1992). Its presence, in conjunction with the non-acid indicator *P. sericea* (section 8.2.4.3), suggests an intermediate (mesotrophic) phase of bog development.

8.2.4.2.5 The aquatic and hygrophilous communities

There are evident expansions in both these categories during this period. The increases amongst the small water-beetles (*Hydroporus* spp.) and the presence of some of the larger predacious water diving-beetles (for example *Agabus bipustulatus* and *Colymbetes fuscus*) indicate larger areas of open water. The Notable B species *Agabus ? chalconatus* is found in leaf- and vegetation-rich standing woodland pools as well as bog pools (Koch, 1989). *Acilius sulcatus* is typical of small lakes and larger ponds with rich marginal vegetation (Nilsson and Holmen, 1995). Many of these Dytiscidae are generalist species or those which live in all types of boggy waters, indicating the lack of truly acid conditions during this phase. There is just one beetle present that has a preference for acid conditions, the Notable B species *Ilybius aenescens*, which lives in pools fringed with *Juncus* and containing deeply flooded *Sphagnum* (Merritt, 1995). Hygrophilous species show clear increases, such as members of the genus *Cyphon*, which would have inhabited damp plant litter and *Sphagnum* in and around these pools.

8.2.4.2.6 The decay community

Most of the comments made previously regarding this community apply.

8.2.4.3 Fossil insect zone 3 (samples 16-15)

This insect zone is characterised by a range of families including Carabidae, Dytiscidae, Staphylinidae, Scirtidae, Chrysomelidae, Scolytidae and Curculionidae. The diverse range of very rare saproxylic species found in the previous assemblage zones is not present, although there is one non-British *Urwaldtier* species.

8.2.4.3.1 The woodland community

There are large increases in species and individuals associated with *Pinus*, characterised by high numbers of *Brachonyx pineti* and *Pityophthorus pubescens*. The former feeds upon the needles of *Pinus* and can reach pest proportions (Bakke, 1958). Whilst these beetles attack live trees, the Notable A scolytid *Pityogenes quadridens* attacks only dying or dead *P. sylvestris* (Lekander *et al.*, 1977) and the non-British *Urwaldrelikt Rhyncolus elongatus* is found in rotting *Pinus* (Palm, 1953). This latter species is frequently associated with the RDB 1 species *Dryophthorus corticalis*, which is also present. This is an *Urwaldtier* associated with old relict forest, often in red rotted wood of deciduous trees, notably *Quercus*, often in association with the ant *L. brunneus* (Shirt, 1987). On the Continent, the species also attacks conifers (Donisthorpe, 1939; Palm, 1959; Koponen and Nuorteva, 1973). In this context on Goole Moors, it was probably feeding on *Pinus*, as argued previously for Hatfield Moors (section 6.6.4.2).

Quercus continued growing close-by, as indicated by its feeder, *Rhynchaenus quercus*. *Scolytus scolytus* suggests the continued vicinity of *Ulmus*, within flying distnace. The Notable B scolytid *Xyleborus ? dryophagus* is found in ancient broad-leaved woodland and pasture woodland and is associated with *Quercus*, as well as *Fagus* and *Ulmus* (Hyman 1992). Taken together, all species indicate the proximity of at least *Quercus* and *Ulmus*. Bracket fungi on any nearby trees would have hosted *Orchesia minor* (Hyman, 1992). *Alnus* is indicated by its feeder *Chrysomela aenea*. *Rhynchaenus foliorum* suggests that *Salix* spp. also grew in the area (Morris, 1993).

There is a paucity of species associated with dead deciduous wood, particularly those specialist saproxylic species that were evident within samples 19, 18 and 17. This suggests that those specimens were associated with the decaying *in situ Quercus*. Once this had been submerged within the peat and plant litter, there was no further suitable habitat for these species, at least in the immediate vicinity. The beetles discussed above are associated with live deciduous trees suggesting that *Pinus*, *Quercus* and possibly other trees continued growing in the general area.

8.2.4.3.2 The heath communities

This community is barely represented, suggesting that *Calluna*-heath was unimportant, although it may not have been entirely absent.

8.2.4.3.3 Non-acid wetland communities

For the first time in the succession, this faunal community is relatively unimportant and is represented by just a few individuals of *Pterostichus diligens* and *P. nigrita/rhaeticus*. *Plateumaris sericea*, indicating more eutrophic conditions, is absent, although the presence of *Psammoecus bipunctatus* indicates the continued presence of aquatic plants such as *Typha, Phragmites, Carex* and *Juncus* tussocks (Koch, 1989).

8.2.4.3.4 Acid wetland communities

In conjunction with the noted decline in rheotrophic-indicating species, there is a marked increase in ombrotrophic species, including *Plateumaris discolor*. The RDB 2 rove beetle *Stenus kiesenwetteri* is found in *Sphagnum* and the litter of *Juncus* and *Eriophorum* (Koch, 1989) and is characteristic of bogs (Hyman, 1994).

8.2.4.3.5 The aquatic and hygrophilous communities

This transition to acid-loving species is also evident amongst the aquatic invertebrates, where there are sharp increases in *Hydroporus tristis* and *H. melanarius*, both of which frequent acid bog pools (Friday, 1988). *Enochrus affinis* is also found in *Sphagnum* pools (Friday, 1988). The continued presence of the larger Dytiscidae, at least in sample 16, suggests sizeable pools of water. However, there is an evident decline in both hygrophilous and aquatic species within the upper sample (15). This is evident amongst the small water beetles *Hydroporus* spp. as well as the wet vegetation-loving members of the Scirtidae family. This abrupt decline in aquatics and hygrophilous species could indicate a temporary drying of the mire surface.

8.2.4.3.6 The decay community

This community is barely represented and does not warrant further comment.

8.2.5 Diversity indices

Figure 8.2 shows the Fisher's α diversity values calculated for the Blackwater Dike site. Apart from Bulk sample 3, the samples show decreasing diversity through the section. Sample 19 displays the highest diversity score of 70, reflecting the richness of the sample and the high numbers of old woodland species. Thereafter, scores range between 35 and 25, reflecting the trend towards acidification. Comparing these scores with Roper's *(1996) (Figure 8.3, third group of figures)*, also from Thorne Moors (point B on Figure 4.3), the scores are similar to those she obtained from between minerotrophic and mesotrophic mire. Roper (*ibid.*) found that in the acid raised mire deposits insect diversity had declined to such an extent that her upper samples scored 6-4 Fisher's α. Insect diversity falls with increasing acidity since such conditions can only be tolerated by a small number of specialist invertebrates (Ball, 1992). Had the full succession been examined, the upper peats would have reflected similar low diversity.

The figures for Blackwater Dike also compare well with Index Values (Figure 8.3) calculated from Buckland' s (1979) and Whitehouse's (1993, 1997a) sites (Points A and C on Figure 4.3). All sites show decreasing biodiversity with acidification.

8.3 Species of note

An outstanding range of rare and endangered species were recovered from the deposits. Table 8.2 illustrates the number of rarities present. These include six non-British species, three RDB1, three RDB2, five RDB3, five NA and nine NB species, mostly consisting of saproxylics and wetland specialists. A total of eighteen non-British species have now been recovered from Thorne Moors (see Table 12.1) (*cf.* Buckland, 1979; Roper, 1993; Whitehouse, 1993). Chapter 12 discusses biogeographical considerations.

8.4 Environmental interpretation

Assemblage zone 1 is characteristic of rheotrophic fen woodland. This community was dominated by *Quercus*, *Betula* and *Alnus* as well as possibly *Fraxinus* and *Ulmus*. *Pinus* was also growing in the vicinity, perhaps living in scattered areas. There are many faunal elements associated with mature, ancient woodland and an abundance of wood, fungi and plant and leaf litter on the woodland floor. *Calluna* and other Ericaceae formed an under-storey beneath these trees. Rheotrophic fen species were associated with sizeable woodland pools, which were fringed with aquatic plants and damp plant litter. Areas of *Sphagnum* spp., *Juncus* spp. and *Eriophorum* spp. were forming.

Insect species	**Host**
Tomicus piniperda	*Pinus sylvestris*
Pityophthorus lichtensteini	*Pinus sylvestris*
P. pubescens	*Pinus sylvestris*
Cryptolestes corticinus	*Pinus sylvestris*
Rhyncolus sculpturatus	*Pinus sylvestris*
R. ater	*Pinus sylvestris*
Rhamphus pulicarius	*Betula* spp.; *Salix* spp; *Populus* spp.; *Myrica* spp.
Rhynchaenus rusci	*Betula* spp.
Rhynchaenus quercus	*Quercus* spp.
Dryocoetinus villosus	*Quercus* spp., *Fraxinus excelsior.*
D. alni	*Alnus glutinosa*, also *Fraxinus* & *Corylus* spp.
Scolytus scolytus	*Ulmus*
Micrelus ericae	*Calluna vulgaris*
Acalles ptinoides	*Calluna vulgaris* (but also from deciduous trees).
Plateumaris sericea	*Carex* spp., *Typha latifolia*, *Iris pseudacorus*, *Schoenoplectus lacustris*, *Bolboschoenus maritimus*, *Sparganium erectum*
Anthonomus rubi	*Fragaria* spp., *Rosa* spp., *Rubus* spp, occ. other Rosaceae.

Assemblage Zone 1: Tree and plant species indicated by the beetles

Assemblage zone 2 is characterised by a strong forest community. *Pinus, Quercus* and *Betula* were important elements. *Fagus* may have been present. The fauna of dying and rotting wood is very important, with many rare and non-British *Urwaldtiere*. Aquatic and hygrophilous species expand, suggesting the growth of areas of open water, probably in response to an increase in the water-table. The mixture of acid and non-acid wetland communities suggests an intermediate (mesotrophic) phase of mire development.

Insect species	**Host**
Tomicus piniperda	*Pinus sylvestris*
Pityophthorus lichtensteini	*Pinus sylvestris*
Rhyncolus sculpturatus	*Pinus sylvestris*
R. ater	*Pinus sylvestris*
Rhynchaenus quercus	*Quercus* spp.
Acalles roboris	usually *Quercus* spp.
Rhynchaenus rusci	*Betula* spp.
Rhynchaenus fagi	*Fagus sylvatica*, occasionally *Quercus* spp.
Rhamphus pulicarius	*Betula* spp.; *Salix* spp; *Populus* spp.; *Myrica* spp.
Rhynchaenus rusci	*Betula* spp.
Scolytus ratzeburgi	*Betula* spp.
Plateumaris discolor	*Carex* spp.; *Sphagnum* and *Eriphorum* spp.
Plateumaris sericea	*Carex* spp., *Typha latifolia*, *Iris pseudacorus*, *Schoenoplectus lacustris*, *Bolboschoenus maritimus*, *Sparganium erectum*

Assemblage Zone 2: Tree and plant species indicated by the beetles

Zone 3 shows an increase in *Pinus*-wood species and decline in deciduous-wood associates. *Quercus* is present, but is less significant than previously. *Alnus glutinosa* and *Salix* spp are present. There are no species associated with *Betula*, but it is likely this tree continued growing on the mire surface. The fauna of dying and dead wood is less important than in the previous samples, probably because it had been living off the now-submerged *in situ Quercus* and associated habitats. The increase in *Pinus*-loving species is associated with a marked decline in rheotrophic indicators and an increase in ombrotrophic species (taxa associated with *Sphagnum* and *Eriphorum* spp.), reflecting a shift in trophic changes from *Quercus*-dominated fen woodland to acid *Pinus*-mire. Aquatics indicate a possible period of mire dryness.

Insect species	**Host**
Brachonyx pineti	*Pinus sylvestris*
Pityophthorus pubescens	*Pinus sylvestris*
Pityogenes quadridens	*Pinus sylvestris*
Rhyncolus elongatus	*Pinus sylvestris*
Aplocnemus nigricornis	*Pinus sylvestris*, but also deciduous trees
Rhynchaenus quercus	*Quercus* spp.
Scolytus scolytus	*Ulmus*
Xyleborus dryophagus	*Quercus* spp., occasionally *Fagus* and *Ulmus* spp.
Dryocoetinus villosus	*Quercus* spp., *Fraxinus excelsior*
Chrysomela aenea	*Alnus glutinosa*
Rhynchaenus foliorum	*Salix* spp.
Psammoecus bipunctatus	*Typha, Phragmites, Carex* and *Juncus* spp.
Plateumaris discolor	*Carex* spp.; *Sphagnum* and *Eriophorum* spp.

Assemblage Zone 3: Tree and plant species indicated by the beetles

8.5 Discussion

8.5.1 The Quercus to Pinus transition (rheotrophic to mesotrophic mire transition)

The *Quercus* (3444-3242 BC) at the base of the succession probably formed a relic of the widespread woodland growing on the Levels between at least 3777-3017 BC (dendrochronological date) (Boswijk, 1998). Previous researchers (Whitehouse, 1993; Dinnin, 1994) and Boswijk (1998) have pointed out that the length and size of the macrofossil *Quercus* trunks suggest growth in relatively closed canopy conditions. The density of trees varied and was probably interspersed with *Betula, Alnus* and other vegetation (Boswijk, 1998). The woodland was multi-aged and naturally regenerating. Regeneration of *Quercus* continued relatively constantly until 3211 BC, after which there was a steady decline until the last tree died sometime after 3007 BC (Boswijk, 1998). This early period is reflected in Smith's pollen diagram from GLM1 (Figure 8.4, a & b) and is probably analogous with his Phase A. This period is represented by pollen of *Betula* and *Alnus* fen wood community, with the development of *Sphagnum* in suitable areas. There are also indications of very wet areas amongst the trees. However, he noted that *Quercus* showed moderate values of only *c.* 10%, suggesting that either this tree was not growing in this particular area of the mire (a suggestion which is partially corroborated by Whitehouse's [1993] insect work in the vicinity) or that the pollen values underestimate the importance of this tree on the mire, perhaps as a result of stress depressing flowering of the trees.

Rheotrophic mire was developing on the northern parts of Thorne Moors (Smith, 1985; Boswijk, 1998), and this probably affected the regeneration of the *Quercus* trees. Mire development occurred faster on Rawcliffe, Snaith and parts of Goole Moor (Boswijk, 1998). On the northern part of Goole Moor scattered *Pinus* trees appear to have superceded the *Quercus*-woodland. Boswijk (1998) suggests that this transition was characterised by early scattered trees that were followed by a sustained growth flush, although density on Goole Moors appears to have been lower than elsewhere and there may not have been a large *Pinus* population during this period. It is difficult to know which of these two phases of *Pinus*-growth is represented at Blackwater Dike, as discussed previously, although it is likely to post-date the early flush of trees and probably represents a period during the first major *Pinus* woodland (2921-2445 BC) (Boswijk, 1998).

The palaeoentomological data provide insights into the nature of the *Quercus-Pinus* transition, illustrated in Figure 8.5. The graph shows the dominance of deciduous woodland-loving taxa up to sample 17, after which there is a rapid decline in this category matched by an increase in pinicolous taxa. Figure 8.6 attempts to illustrate this transition. The earlier period is characterised by species associated with *Quercus*, *Quercus/Fagus/Ulmus*, interspersed by at least *Betula* and some *Alnus*. *Pinus*-loving species are present, suggesting the low-level presence of this tree during this earlier stage. Mire development had already been initiated, and the fauna is indicative of rheotrophic fen woodland conditions, which are consistent with Boswijk's findings as well as Smith's (1985) palynological work. By the time sample 16 (assemblage zone 3) was deposited, *Pinus* must have been the dominant tree on the mire. There were also small numbers of species associated with *Salix* spp as well as *Quercus*.

In order to examine the causes behind this transition, the frequency of the aquatics, acidic and non-acidic species and tree species (excluding dead wood taxa) was also plotted (Figure 8.7). The three plots illustrate several points. Firstly, there appears to have been a peak in aquatics during assemblage zone 2, which declines towards the top part of the sequence. The insect data clearly indicate the onset of wetter conditions, even during this earlier phase. It is noteworthy that the peak in wet conditions mirrors the peak in deciduous-loving taxa. Non-acid loving taxa also peak during this period, after which they decline. This decline is matched by an increase in acid-loving taxa, and the curve for these species appears to mirror that of the coniferous-loving taxa. These factors suggest that acidity and water levels are positively correlated with the transition from deciduous- to coniferous-dominated woodland. The peak in aquatics and deciduous woodland would at first appear somewhat of an anomaly, but is probably best explained as the product of a time-delayed effect between the death of the deciduous woodland and the high water-levels. It is likely that deciduous trees growing on the mire may have been able to tolerate some higher water levels, but that the germination of young trees is likely to have been affected by such levels. The effect of this would have been to cause the decline of deciduous trees. The increase in acid-loving taxa suggests the onset of more ombrotrophic conditions. The combination of such factors, coupled with the apparent decline in water levels, suggesting a period of mire dryness, may have allowed *Pinus* to dominate the woodland growing on the mire surface and not allowed more nutrient-demanding taxa to re-colonise the area. Other factors may also affect the regeneration of deciduous trees. These range from unfavourable environmental conditions (including unfavourable climate), the inability of seedlings to tolerate shading and the effects of defoliating caterpillars dropping from over-storey trees, and fungal attack (Worrell and Nixon, 1991). *Pinus*, on the other hand, is typical of the transition stage from fen to raised mire as it is able to tolerate acid and wetter conditions than most deciduous trees (Godwin, 1975). Thus, by the time sample 16 was deposited, the mixed deciduous woodland had become moribund and given way to *Pinus* woodland. However, this may be only part of the explanation (see below, 8.5.2).

This stage of ecological change is probably analogous with Smith's Phase B (1985). This period shows high arboreal pollen values, demonstrating the presence of dense forest surrounding Thorne Moors (Smith, 1985, Figure 8.4 a, b). This forest apparently consisted of *Quercus*, *Corylus*, *Tilia*, *Ulmus* and *Fraxinus*, with *Alnus*, *Betula* growing on the developing mire. Some of the *Quercus* represented in the diagram, at least during the earlier part of the phase, must also have had a rather more local origin. Smith (*ibid.*) also identifies a rapid invasion of *Pinus* that he suggests is related to a temporary drying of the mire surface (Smith, 1985). This phase is clearly reflected in the fossil insect data discussed above. This rapid expansion period was followed by an equally rapid decline in *Pinus* pollen, prior to the charcoal horizon in the peat. This decline is not represented at the Blackwater Dike site, probably since not all the deposits in the sequence were examined. However, this event is illustrated by the abrupt decline in pinicolous taxa on the eastern side of Thorne Moors (Roper, 1993, 1996) and coincides with the onset of ombrotrophic conditions.

Taking all the palaeoecological data together (Buckland and Kenward 1973; Buckland 1979; Smith 1985; Roper, 1993, 1996; Whitehouse, 1993, 1997a; Boswijk, 1998), it appears that the area was formerly covered by a mixed deciduous, *Quercus*-dominated forest, which was then superseded by a mixed *Pinus-Betula* forest, with *Quercus* forest persisting in certain areas. Boswijk's (1998) research illustrates how the spread of the mire progressed in a series of pulses, separated by phases when *Pinus* could colonise marginal areas. The palaeoentomological sequence at Blackwater Dike highlights the development of one of those phases. The forest then became moribund through increasing water-levels and acidification, becoming engulfed by the growth of rheotrophic and mesotrophic mire. Thorne Moors thus displays a very clear transition from wet *Quercus-Alnus-Betula* fen woodland through to *Pinus-Betula* woodland to mesotrophic mire. This transition was delayed in some areas, notably on the south side of Thorne Moors in the vicinity of the Bronze Age trackway. Here, Buckland (1979) found the remnants of the fen *Urwald* woodland, together with its associated fauna, about *c.* 1200 years after peat initiation elsewhere (1680-1440 cal BC, 3260 ± 100 BP, BIRM-335). The fen peats here gave way to ombrotrophic peat shortly after 1390-1060 cal BC (2980 ± 110 BP, BIRM-358). Figure 8.8 shows the distribution of all the relevant basal dates for Thorne Moors.

8.5.2 Evidence of fire

Samples 18 and 17 contained fragments of charcoal. The size and nature of the charred material (charred *Calluna* and wood) suggest this represents the remains of an *in situ* fire. The fire may not have been very extensive, possibly very local in extent, burning the surface vegetation. Charred material has been noted elsewhere on Thorne Moors and been the subject of extensive review and discussion (*cf.* Whitehouse, 1993, 1997a; Dinnin, 1994; Dinnin, 1997c; Boswijk, 1998). The distribution of this burnt wood (Figure 8.9) appears to be mainly confined to the north-western and central parts of the Moors and restricted to *Betula* and *Pinus* trees (Whitehouse, 1993, 1997a; Dinnin, 1994; Boswijk, 1998). Pollen site GLM 1 (Smith, 1985) contained a charcoal horizon *c.* 40 cm from the base, which was dated to 2280-2030 cal BC (3715 ± 70 BP, CAR-233). Elsewhere, a date of 2030-1770 cal BC (3545 ± 70 BP, CAR-313) was obtained for a burnt *Pinus* on Crowle Moor and 2130-1910 cal BC (3620 ± 60 BP) for a charcoal horizon at Smith's (1985) CLM 2 site (*c.* 100 cm from base). These dates suggest a fire event/multiple fire events sometime *c.* 2,000 cal BC. The dates could reflect a gap of several hundred years between burning events. Boswijk (1998) also identifies two periods when conditions may have been suitable for fire, at 2056 BC and 2017 BC, although she points out that the evidence is strongest for an event around 2056 BC. These dates fall within the calibration range of the charcoal horizons noted by Smith (1985). There is very little stratigraphic evidence of charcoal or burning through the peat body (Dinnin, 1994).

However, at the Blackwater Dike site charcoal was noted *just c.* 15-20 cm above the basal deposits. Peat initiation in this area probably commenced sometime *c.* 3400-3100 cal BC. Whilst it would be difficult to calculate the rate of peat deposition without other radiocarbon dates, it seems unlikely that the charcoal observed in this profile relates to the same event or series of events noted elsewhere at *c.* 2,000 cal BC: this would mean that just *c.* 15-20 cm of peat deposition had formed over a 1400-1200 year period. It is thus possible that these samples contain evidence of burning on Thorne Moors sometime between *c.* 3400-3100 cal BC and *c.* 2000 cal BC. Boswijk (1998) identifies a narrow tree-ring episode at 2575-2570 BC, which she suggests could be related to a fire episode, although the evidence is not convincing. It is feasible that the charcoal noted may relate to this possible fire event. However, charcoal appears to be positively correlated with the onset of the *Pinus* woodland, which could be tentatively correlated with Boswijk's (1998) first major *Pinus* woodland (2921-2445 BC). This could potentially place a fire event *prior* to the *Pinus* chronology (that is, pre- 2921 BC). On stratigraphic grounds this date seems more acceptable, with 25 cm of deposit representing *c.* 200-400 years of peat deposition. Boswijk (1998) found no evidence of a fire at such an early stage, although she recovered a single charred tree from the early *Pinus* group dated to 3225 BC. This tree could, of course, have been burnt sometime *after* its death.

It thus appears possible that the charcoal noted at Blackwater Dike represents evidence of another fire on Thorne Moors that pre-dates those previously identified. Boswijk (1998) highlights three main periods of *Pinus* growth, with fires possibly occurring towards the end of each phase or sometime afterward. Fire was probably not directly responsible for killing the trees and stimulating the spread of the mire, rather that a shift to wetter conditions is likely to have been the primary cause of woodland decline (Boswijk, 1998). Boswijk (*ibid.*, 121) identifies three or four dates for potential fire events during the period covered by the dendrochronological study (2570-2560 BC [PISY chronology]; 2056 or 2017 BC, two dates where growth depressions and recoveries may indicate fires [GM01 chronology]; after 1518 BC (GM02 chronology]) and concludes that fire occurred *after* the demise of the woodland. These interpretations were made on the basis of sudden changes in growth trends and occurrences of dead trees being charred; there was no direct evidence based on fire scars. As Boswijk herself points out, other factors such as changes in water-levels on the mires could have affected the growth trends of some of these trees. *Pinus* has an extraordinary ability to survive forest fires (Zackrisson, 1977). The lack of fire scars and the combination of charred edges as well as bark edge indicates that many trees were moribund or dead when fire swept across the area (Boswijk, 1998).

A burnt *Pinus* tree investigated by Whitehouse (1993, 1997a) for its fossil insect fauna on the western side of Thorne Waste (C on Figure 4.3) supports this hypothesis. The proliferation of dead-wood invertebrates indicate an abundance of dead wood and coarse woody debris and suggest that the trees were already moribund *prior* to any burning. The presence of pyrophilous invertebrates indicates that a fire swept the area when the trees were still exposed on the surface of the mire (Whitehouse, 1993, 1997a). A species of beetle was recovered during this previous study that could not be identified at the time (Species A of Whitehouse, 1993) and was subsequently identified as a non-British anobiid, *Stagetus borealis*. This is a largely pinicolous species that is found mainly *5 to 25 years after fire, on polypores* (Wikars, 1992).

There is at least one other episode of mire fire recorded from Thorne Moors besides those discussed above, associated with the Bronze Age trackway (Buckland and Kenward, 1973; Buckland, 1979) (Point A, Figure 4.3). Close to the structure was the stump of a burnt *Quercus* tree, which was radiocarbon dated to 1450-1220 cal BC (3080 ± 90 B.P., BIRM-336). This suggests that burning occurred in this area at least 550-780 years **after** the *Pinus-Betula* forest burnt. Peat in this section of the Moors is at a greater depth than elsewhere, and its vegetated state may obscure evidence for other burnt trees in the peat. Peat workers hand peat-cutting this area in the 1970's confirm the presence of large burnt *Quercus* (I. Edwards, *pers. comm.,* 1994). The association between the burning and the trackway led Buckland and Kenward (1973) to argue that the burning represented evidence for clearance activities by local late Bronze age people.

The correlation between the charcoal horizon and the expansion of the pinicolous fauna (and its host) demands attention. Besides those factors already identified, fire may have played an important role in the transition from deciduous- to coniferous-dominated woodland. Kuhry (1994, 903) noted in two *Sphagnum* bogs in boreal Canada that the macrofossils of *Pinus* and ericaceous taxa become temporarily more abundant directly above a charcoal horizon. In Sweden, Bradshaw (1993) noted a transition from deciduous to boreal forest occurring abruptly after a series of massive fires. A positive correlation between *Pinus* pollen values and macroscopic charcoal has been noted at several sites (O'Sullivan, 1991; Engelmark *et al.*, 1994) and the importance of fire in coniferous forests has been extensively researched (for example, Zackrisson, 1977; Hyvärinen and Sepponen, 1988). *Pinus* regeneration appears to benefit from natural as well as human-made disturbance, with large areas of woodland regenerating after burning (Uggla, 1958; Carlisle, 1977; Engelmark, 1987). Burning of the vegetation in the *Quercus-Betula-Alnus* fen may have had the effect of promoting the germination of *Pinus* seed in this area.

8.5.3 Comparison with previous palaeoentomological work on Thorne Moors

Four different locations have now been examined for their fossil entomofaunal record on Thorne Moors (see Figure 4.3). The sites provide a good range of assemblages across the Moors (Buckland, 1979; Roper, 1993; Whitehouse, 1993). The most striking aspect of all these assemblages is the massive proportion of saproxylic fossil beetles, attracted to the large number of mature, dying and moribund mire trees. It has been argued elsewhere that this woodland probably did not die as a result of fire(s), but probably as a result of increasing water-levels and acidification as the bog developed into ombrotrophic mire. This process generated a large amount of dead wood on the mire surface, although prior to the woodland's death there was also an abundance of saproxylic species. The faunas are typical of undisturbed, long-lived climax natural forest, or *Urwald*, an ecosystem which no longer exists in Britain today and which is increasingly restricted in Europe to a few forests of considerable antiquity (Speight, 1989). Large standing and fallen dead trees are a feature of such forests. This component can range from between 10% (Östlund, 1993) to 50% of the woodland trees in undisturbed forests (Elton, 1966) and may have composed even higher percentages of the forest composition. There is also a gradient in the quantity of dying timber lying in undisturbed forests according to climate. In temperate woodlands there may be dense layers of fallen timber accumulated; large *Fagus* trees can lie on the forest floor for a quarter of a century or more (Elton, 1966). The removal of these elements from the forest ecosystem has strongly affected the biological diversity of such forests (for example, Elton, 1966; Heliövaara and Väisänen, 1984; Speight, 1989; Östlund, 1993; Kaila *et al.*, 1997).

The fossil insect studies illustrate the importance of taking a multi-proxy approach to examining palaeoecological evidence and highlight some of the pitfalls when just palynological studies are pursued in isolation (Buckland, 1976). For instance, some of the Thorne Moors phytophagous taxa reflect the presence of trees on the mire itself: *Quercus* was growing on the rheotrophic mire deposits and *Salix, Fagus* and *Ulmus* may also have been growing on or very close to the developing mire. The assemblages also reflect some of the changes occurring on the mire that are less easily distinguishable in pollen diagrams. *Pinus*-loving taxa highlight the importance of this tree on mires and indicate how its importance may have been under-estimated within the palynological analysis. Boswijk (1998) identified at least two episodes of *Pinus* woodland that were not obvious from Smith's (1985) pollen data. The date span for the GM01 chronology (Boswijk, 1998) overlaps Smith's (1985) *Pinus* decline, *c.* 2280-2030 cal BC (3715 ± 70 BP, CAR-233), whilst the last dated *Pinus* died in 1489 BC, at least 500 years later.

The fossil insect assemblages highlight the considerable loss of habitat associated with coniferous woodland, particularly with *Pinus sylvestris*, reflecting the loss of this tree from the English landscape. *Pinus* had, by the Bronze Age, become restricted to marginal areas, such as developing peat bogs. Other elements of this ecosystem appear to have been affected by losses, such as habitats associated with mature *Betula* and with fire.

CHAPTER IX: THORNE AND HATFIELD MOORS: SUMMING UP THE MIRE ASSEMBLAGE RESULTS

9.1 Introduction

This chapter presents the results of the correspondence analyses carried out on the mire assemblages. A discussion on how well the fossil mire assemblages compare with the modern Coleoptera which inhabit the Moors follows.

9.2 Correspondence analysis

The aim of the correspondence analysis was two-fold:

- Investigate the levels of faunal similarity/dissimilarity between assemblages from the two mires (sample plots).
- to explore if certain species consistently occurred together and reacted to the same stimuli (e.g. moisture, acidity) and to elucidate the extirpation of the non-British species recovered (species plots).

To aid the interpretation of the plots, Tables 9.1-9.2 provide information on the samples/species analysed and are included in a wallet at the back of the thesis, as well as in the appropriate Tables section in Volume 2.

9.2.1 Sample plots

All samples were numbered for this analysis. Table 9.1 lists the number given to each sample. The sample plots show the relationships between different samples. Figure 9.1 shows the results of the CA analysis on the samples (please note quadrant letters). Although not all samples are displayed in this plot, a very striking result is displayed: the samples from Thorne and Hatfield are very different to one another. Whereas Hatfield samples are clustered together, almost homogeneous, the Thorne Moors samples display a wide distribution. This relationship is further displayed in Figure 9.2, which is an enlarged version of the previous figure. Whereas the Hatfield Moors samples cluster around the point of origin of the graph, the samples from Thorne Moors appear in different clusters, which suggests that not only are the samples different from Hatfield Moors, they are heterogeneous *across* Thorne Moors itself.

Figures 9.3-9.6 (quadrants have been enlarged to allow a higher resolution of the data to be displayed), display these differences at palaeoecological site-specific level. Thus, samples from Goole 1 (Roper, 1993, 1996) (Figure 9.3) display an almost linear distribution which appear to illustrate the faunas' increasing trend towards acidification. Samples containing more ombrotrophic-loving species are plotted towards the margins of the graph. There are few other samples which show any similarity to these assemblages. Thus, the samples displayed within quadrant C (see Figure 9.1 for position of each quadrant) seem to be affected by levels of acidity.

In contrast, the trackway samples (Thorne) (Buckland, 1979) are illustrated in Figure 9.4. Once again, the striking aspect of this graph is the homogeneity within the trackway samples and their distance from the main cluster of samples, indicating their uniqueness amongst the assemblages examined. The dominance of these samples by deciduous wood-loving species is likely to be the factor which separates these samples from the rest. Figure 9.5, on the other hand, illustrates that the samples from Blackwater Dike appear to have more elements in common with assemblages from Hatfield Moors. This probably relates to the higher proportions of *Pinus*-loving taxa within these assemblages. It is interesting that point 35 (= sample 19) is more closely correlated with the trackway samples; the dominance of deciduous-wood taxa within this sample is likely to explain its position in the plot. The other samples within the assemblages are more heavily dominated by *Pinus*-loving taxa, and this would explain the observed patterns. Thorne Moors 2 (Whitehouse, 1993, 1997a) is displayed in Figure 9.6, and since these samples were heavily dominated by pinicolous taxa, this would appear to confirm that these samples are those more closely associated with *Pinus*-habitats.

Turning to the results from Hatfield Moors, these are displayed in Figures 9.7-9.8. HAT 3 and 4 are highlighted in the former figure. The two samples from HAT 3 are clearly closely correlated, and this is evident from the discussion of the samples (section 6.2). HAT 4 has a more dispersed distribution of points and appears to lie on the periphery of the other Hatfield samples. This is not entirely surprising given the rather different nature of this assemblage compared with the others, not least because of the presence of rheotrophic-indicating taxa at the base of the sequence. Indeed, it is interesting that the basal samples, represented by points 1, 2 and 3 (=samples 29-27), are closely allied to basal samples from Goole Moors 1 (Roper, 1993, 1996), which also contained a good range of rheotrophic-indicating taxa. It would thus appear that the early stages of mire development at these two locations on the Moors were entomofaunally very similar. However, by the time sample 16 (=point 11) had been deposited, something dramatic appears to have happened. This sample coincides with the onset of fossil insect assemblage zone 3a and the transition from mesotrophic to ombrotrophic mire. The HAT 4 samples distributed towards the top of quadrant B are samples reflecting ombrotrophic species. More interestingly, it might be asked why the points are plotted in a different direction to those at Goole 1, especially since their environmental interpretation indicates that both assemblages are ombrotrophic. The answer must surely be that whilst both assemblages reflect the onset of ombrotrophic conditions, these were markedly different across the two sites. The Hatfield Moors samples probably reflect their wet heath character, a characteristic which is not evident amongst the fossil Coleoptera from Thorne Moors. The subtle, but real differences, between these two sites are well illustrated within this graph.

Figure 9.8 illustrates the distribution of the LIND A, B and TYRHAM samples. The majority of these samples are concentrated within quadrant A. They seem to be fairly closely correlated with each other, suggesting their overall faunal homogeneity. Most of these faunas are heavily dominated by *Pinus*-loving taxa.

Relating back to the first aim outlined for using the analysis, the results visually corroborate the interpretation that the fossil faunal composition on the two mires is different, in some instances very different. Despite some differences, the assemblages from Hatfield are more homogeneous than those from Throne Moors. In contrast, the Thorne Moors samples are heterogeneous, particularly at palaeoecological-site level. Factors which might have affected such disparity could relate to the genesis and development of the Moors. It has been previously argued that Hatfield Moors may have developed in a more-or-less simultaneous uni or poly-focal manner (section 7.8.3). Such development could have created the more homogeneous fossil insect assemblages. On Thorne Moors peat initiation was delayed in certain areas by about 1000-1300 years (see Figure 8.8). The fact that later peat initiation dates appear to be distributed in a non-linear, temporally disjunct fashion, suggests that peat initiation occurred in a time-transgressive manner, creating a mosaic of different habitats, thus creating the temporal and landscape heterogeneity visible in some of the CA plots.

9.2.2 Species plots

Table 9.2 lists the species which were included in the analysis; readers are referred to this table for the list of abbreviations used in the plots. Although CANOCO revealed interesting and worthwhile results amongst the sample plots, the species plots were less easily interpreted in ecological terms. Figure 9.9 shows the results of the species CA analysis. This plot shows a messy distribution of species. In order to make sense of the results, quadrants were enlarged to allow a higher resolution of the data to be displayed. Although some species associations were apparent, much of the data did not make any particular ecological sense. Figures 9.10-9.11 show two of the evident associations. The first plot shows the co-occurrence of *Pterostichus minor, P. diligens, Pterostichus* spp. and *Agonum obscurum*. Research carried out on upland mires in Wales has demonstrated the association of these species (Holmes *et al.*, 1993). Figure 9.12 highlights the close association between *Rhyncolus sculpturatus* and *Dryopthorus corticalis*, an association noted by the author previously. The former species is now extirpated from Britain, whereas the latter is restricted to Windsor Forest (Hyman, 1992). This association could provide information regarding the extirpation and contraction of both species.

In order to try to make further sense of the data, species were also coded using the ecological grouping system (Figure 9.12). Unfortunately, this did not elucidate any of the observed patterns, even when the quadrants were enlarged. It is probable that the high number of species which were excluded from the analysis may have had a detrimental affect in the outcome of this analysis. The high number of rare species in the mire assemblages is likely to have been due to temporal as well as landscape heterogeneity within the assemblages, a point which is well-demonstrated above.

9.2.3 The use of CA in the analysis of fossil insect assemblages

Whilst CA appeared to show interesting trends at sample / palaeoecological / landscape level, it did not yield particularly useful results for examining patterns at species level.

Several observations can be made with regard to using this technique to examine species associations. Firstly, it may have yielded more promising results if it had been utilised on small, confined, assemblages, where the *range* of species is relatively restricted and where the same species might be expected to occur. Appropriate faunas might be archaeological assemblages. Natural assemblages, on the other hand, contain a very diverse range of species and a large number of species may only occur in a few samples (i.e. there are many "rarities"). Two possible approaches could address this problem, which are, however, outside the scope of this thesis. Firstly, the data-base could be expanded and a larger number of samples from a range of similar contexts could be added to the analysis (e.g. samples from other mire deposits). It should be noted that very few comparative assemblages exist. The other possibility would involve including the rare species within the analysis. The most obvious way of achieving this would be to classify the species into groups. Such a classification system would require much thought and input, however, as each member of a category would have to share a number of aspects in common with the other members of the group. A classification system based entirely upon habitat, for instance, may not be appropriate, since other environmental factors may be equally important within species associations (e.g.

moisture of wood; longevity of habitat; acidity). Finally, meaningful results might be achieved by using just presence/absence data, although this approach would place an undue emphasis upon rare types and not fully examine the dynamics between common species.

Whilst this technique has yielded some interesting results, it is apparent that much further work needs to be undertaken before this application's full potential can may be evaluated.

9.3 Comparisons with present data

Only 50% of the beetle species found fossil are on the present invertebrate list for Hatfield Moors. In comparison, almost 83% of the fossil beetle species from Thorne Moors still inhabit the site. The reason for this disparity is likely to reflect the history of modern invertebrate-collecting and recording on Hatfield Moors, although it is probable that a small portion of species recovered as fossils may no longer live on these Moors. Historically, Hatfield Moors has been less intensively studied for its invertebrates compared with Thorne Moors, to the point of neglect (Eversham, 1997b). Because of its proximity to Thorne Moors many naturalists dismissed Hatfield Moors as its "poor neighbour" and in consequence much of the survey work, until recently, has concentrated on the former site (Skidmore, *in press*).

No formal survey work on Hatfield was undertaken until the late 1980's (Heaver and Eversham, 1991) and was carried out after large-scale milling had initiated. Much of this work was concentrated on those areas which are not milled, around the southern area of Packards south and Poor Piece and more recently on Lindholme Island (Skidmore, *in press*). Much of the species list is therefore bias towards these particular localities and still far from complete (Skidmore, *in press*). Had there been an opportunity to carry out survey work before large scale peat cutting, it may have been possible to evaluate whether any of the rare saproxylic and wetland species which are evident in the fossil record had managed to survive in the area until recently. This makes comparison between fossil and modern lists problematic. What is clear, however, is that Hatfield Moors supports a wider and more varied woodland fauna than Thorne Moors and that grassland and wet heath are very important elements of this mire's faunal assemblage (Skidmore, 1997; *in press*). Despite being badly damaged by peat extraction, Hatfield Moors still retains an incredibly rich fauna and remains a site of major national importance (Skidmore, *in press*).

The fossil insect work allows the modern invertebrate work to be placed within a temporal perspective, and suggests that Hatfield was once as rich in invertebrate species as Thorne Moors. The work indicates that some of Thorne and Hatfield's national endemics have been present on the site for several thousand years, such as beetles *Bembidion humerale* and *Curimposis nigrita,* which have both been recovered as fossils from the Moors. *C. nigrita* was first found as a fossil associated with the Bronze Age trackway on Thorne Moors (Buckland and Johnson, 1984). Both species have been recovered from Hatfield Moors. *Bembidion humerale* was recovered from the LIND B sequence, (sample 15), dating from between < 2700-2350 cal BC (3990 ± 60 BP, BETA-91800) and > 1130-840 cal BC (2820 ±50 BP, BETA-91799). *Curimopsis nigrita* was recovered from sample 1 at Tyrham Hall Quarry, dating this specimen to *c.* 3000-2400 BC (dendrochronological date).

9.4 Faunal longevity and stability

There are many other faunal elements from both sites which still appear on the modern Coleopteran list. This continuity of species underlies the stability and longevity of the faunal communities of these sites, a stability which is ever-more threatened by the continued degradation of the mires through peat cutting and drainage. The remarkable stability documented within the palaeoentomological record of these mires appears to be featured at other similar sites, although, as noted previously, very few mire successions have been studied for their fossil insect fauna. Lavoie *et al.* (1997) noted the remarkable stability of the entomofauna of a peat bog in Canada through a 7,000 year sequence. They found that their faunas did not appear to have been influenced by overall climatic events of the period represented by the deposits. They suggest that peatlands are buffered environments which are not very sensitive to climate change and that many of the species living on the bogs were responding primarily to local hydrological conditions and/or food sources rather than climate. However, they also point out that the climatic changes of the last 7,000 years were probably not large enough to initiate shifts in insect distribution. Issues concerning any climatic significance of the assemblages from the Humberhead Levels are discussed more fully in Chapter 12. However, the stability of the mire faunas appear to support Lavoie *et al.*'s (1997) statement.

It is clear that very few comparable sites to Thorne and Hatfield Moors have been studied from a fossil entomofaunal perspective. There are no comparable European sites which today support the range of invertebrate species which formerly used to live on the Moors. The question which might be asked is how does this fauna compare with other sites of comparable date - were British Holocene woodlands formerly as rich in invertebrates as the data from Thorne Moors (and Hatfield Moors) appear to suggest? Are these sites unique on a regional and national level? There are comparable sites at a national level, notably from the Somerset Levels (*cf.* Girling 1979a; 1985) and elsewhere (Girling, 1989; Robinson, 1991), although even here the data is not as rich or abundant as on the Moors. Perhaps the only other palaeoentomological site which displays the same faunal richness as the Moors comes from a raised mire in Finland (Koponen and Nuorteva, 1973). However, it is unclear how the mire assemblages compare with other sites of similar date in the Humberhead Levels. It was partially to address these questions that the floodplain assemblages, described in the next chapter, were examined.

CHAPTER X: THE FLOODPLAIN DEPOSITS: PALAEOENTOMOLOGICAL INVESTIGATIONS OF HAYFIELD LODGE FARM, ROSSINGTON, AND MISTERTON CARR.

10.1 Introduction

The sequences from Rossington and Misterton Carr offer a regional context within which the mire assemblages may be compared. The sequences also allow the Humberhead Levels' landscape and vegetational development to be examined across a transect, from the raised mires to the Sherwood Sandstone outcrop and river valley floodplains. In addition, there appears to be an intrinsic association between floodplain wetland development and the origins and development of the raised mires. The often intimate association between the floodplain deposits and archaeological sites also makes these sites valuable deposits in their own right.

10.2 Hayfield Lodge Farm, Rossington

Hayfield Lodge Farm, Rossington Bridge, near Doncaster, is located *c.* 10 km south of Hatfield, on the River Torne floodplain. The palaeoentomological site is located *c.* 700 metres from Mather's (1991) palynological sequence (Figure 4.4).

The floodplain and surrounding uplands in the vicinity of Rossington Bridge are located in an archaeologically-rich area (Head *et al.*, 1997b), with sites and finds dating from the Mesolithic to the post-Roman period. As previously noted (Chapter 2), the distribution of Mesolithic finds in the Humberhead Levels seems to coincide to a high degree with the presence of rivers or their palaeochannels (Van de Noort and Fenwick, 1997, 223). The River Torne is no exception to this pattern. Isolated finds of this period and later have been recovered (Buckland and Dolby, 1973; Mather, 1991; Head *et al.*, 1997b). The river banks and associated wetlands were presumably exploited for a number of different wild resources.

The area around the Torne floodplain is well known for its extensive field system crop marks (Riley, 1976, 1980, 1983; Chapman, 1997), for instance at Littleworth, Rossington, (Riley, 1988). The uneasy relationship shown by the position of the Roman vexillation fortress at Rossington (south of Hayfield Lodge Farm) and the field system suggests that these boundaries date to *prior* to the construction of the Roman fort (Buckland and Magilton, 1986; Riley, 1996), dated to *c.* 46-55 AD (Buckland, 1997). A crop mark site near Rossington has been excavated, but none of the features produced any finds and the chronology of construction and abandonment remains in some doubt (Chadwick, 1993). The dating of these boundaries continues to be a source of debate (Magilton, 1978; Riley, 1980; Buckland 1979; Chapman, 1997), but many appear to at least pre-date the Roman period and indicate an open landscape at this time. There is little evidence for the crops and stock that may have been kept in these fields, although a Roman corn-drying oven has been excavated at Womersley (Buckland and Dolby, 1987) and grain pests have been recorded from Sandtoft (Samuels and Buckland, 1978).

The palaeoentomological site at Hayfield Lodge Farm lies immediately south of the Rossington Bridge Scheduled Ancient Monument (SK 633996) (see Figure 4.4). This site consists of several hectares of Roman occupation, including the most important known concentration of Romano-British pottery kilns in the region. A total of sixteen pottery kilns has been located in this area, dating from the mid 2nd century AD onwards (Buckland *et al., in press*). A wide range of pottery was produced at the site, including mortaria of the potter SARRIVS (Buckland *et al., in press*). This site formed part of a large Romano-British pottery industry, with kilns in Cantley, Bessacarr, Branton (Buckland, 1976b) and Blaxton (Buckland and Dolby, 1980), as well as Rossington (Buckland *et al.*, 1979). The industries probably utilised the rivers Torne and Don to distribute their wares (Buckland *et al.*, 1979), as well as the Roman road from Lincoln to York, which crosses the Torne *c.* 100-150 metres from the palaeoentomological section, en route to Doncaster (Buckland and Magilton, 1986).

Because of the site's proximity to the Scheduled Monument, some evaluative archaeological work was carried out in the area excavated for the fishing sports centre in 1992-93 (Atkinson, 1993). Unfortunately, the landowner had removed much of the peat, leaving a limited area to be evaluated. No archaeological finds were recovered, but some areas of heat cracked stones were recovered.

10.2.1 The palaeoentomological samples

Twelve fossil insect assemblages were examined, representing 1670 MNI, across at least 334 species, from 42 families of Coleoptera. Figure 4.11 shows the stratigraphic relationships between samples. Table 10.1 lists the insect fossils recovered. Appendix C provides details of all the samples processed (including levels of preservation) and Appendix D discusses any identification problems. Most assemblages were well preserved, scoring 4 on the Preservation Index, although basal samples 20 and 19 scored 2/3 on the Index. Some of the upper samples were less well preserved (for example, sample 7, scoring 1 on the Index).

10.2.2 Age of the deposit

Palynological evidence (Mather, 1991) suggests that detrital peat deposition in the Torne floodplain commenced during the early Holocene (*c.* 8000 uncal BP or 7000 cal BC), and was terminated by an episode of alluviation, elsewhere in the Levels dated to the late Roman period (Buckland and Sadler, 1985). However, since the sequence examined may have belonged to a separate meander of the River Torne, a new series of radiocarbon dates was obtained for this site. Table 5.3 tabulates the relevant dates for the Humberhead Levels, but the appropriate dates are also reproduced here:

River Torne	5340 ± 45	SRR-6136	3.40 m	Base of channel	4340-4040 BC
	3990 ± 45	SRR-6135	3.25-3.15 m	Charcoal layer	2620-2450 BC (0.91) 2860-2820 BC (0.04) 2660-2640 BC (0.02) 2430-2390 BC (0.03)
	3145 ± 45	SRR-6134	3.00-2.95 m		1520-1370 BC (0.91) 1350-1310 BC (0.09)
	3330 ± 45	SRR-6133	2.85-2.75 m		1740-1520 BC
	3210 ± 45	SRR-6132	2.65-2.55 m		1610-1410 BC
	3290 ± 45	SRR-6131	2.45-2.35 m		1690-1450 BC
	2290 ± 45	SRR-6130	1.80-1.70 m	Top of peat	410-190 BC
	2540 ± 50	SRR-6129	1.60-1.50 m	Alluvium	820-510 BC
	1755 ± 50	SRR-6128	1.40-1.20 m	Top of organic deposits (alluvium)	130-400 AD

These dates indicate that the sequence covers the period from 4340-4040 cal BC to 130-400 cal BC (5340 ± 45 BP [SRR-6136] to 1755 ± 50 BP [SRR-6128]), covering a period of *c.* 4100-4700 calendar years.

The new dates indicate that basal peat deposition began around 4340-4040 cal BC (5340 ± 45 BP), in this area, a later date compared with Mather's (1991). Two possibilities could explain this difference. Firstly, Mather's evidence was based entirely on palynological data. He believed that the earliest period represented by the pollen data pre-dated any of Smith's (1985) regional pollen assemblage zones (HHL/A, dated to *c.* 3500 cal BC). He suggests that the presence of thermophilous trees such as *Tilia* indicated at least an early Holocene date. Birks' isochrone maps (1989) show that *Tilia* had reached the area at least by 7000 BP (*c.* 5800 cal BC). Mather also noted an *Alnus* rise in his zone HLF 2/a. The radiocarbon date of 5360-5070 cal BC (6290 ± 70 BP, Beta-75272, [Brayshay and Dinnin, *in press*]) for the *Alnus* rise at Bole Ings, Nottinghamshire, provides the only date for this event in the Humber basin (Brayshay and Dinnin, *in press*), although the asynchroneity of the *Alnus* rise means that it is problematic to use this chronostratigraphic marker over wide areas (Chambers and

Elliott, 1989; Bennett and Birks, 1990). In addition, local edaphic factors are likely to have been important in the expansion of *Alnus* in many areas and thus such events in pollen profiles are likely to correspond to local environmental changes (such as the onset of wetter conditions in floodplains). It thus seems likely that detrital peat deposition at Mather's site began at least around *c.* 6000-5000 cal BC and it is possible that he may have over-estimated its age.

However, the disparity in dates may also be explained if the two sequences related to separate meanders of the River Torne. The rivers in the Humberhead Levels meandered widely over this area, often creating more than one channel. The distance between the two sites could mean that the peat deposits relate to different, although probably overlapping, periods of floodplain development. This interpretation appears the most likely explanation.

The top of the palaeoentomological sequence is sealed by a thick layer of alluvium, which dated to 130-400 cal AD (1755 ± 50 BP, SRR-6128), placing this event to sometime in the late Roman period. Similar changes in fluvial deposition at Sandtoft, close to the confluence of the Don and Idle, of which the Torne is tributary, were noted by Buckland and Sadler (1985), which were stratigraphically dated to the late Roman period. The alluvium date from Rossington would support this evidence.

10.2.3 Results

Members of the families Carabidae, Dytiscidae, Hydraenidae, Hydrophilidae, Staphylinidae, Dryopidae, Chrysomelidae, Scolytidae and Curculionidae dominated the faunal assemblage. One non-British species was recovered, *Rhyncolus punctulatus*, which has been previously recovered from from Thorne (Whitehouse, 1993), Hatfield Moors (Chapter 6) and Stileway, Somerset (Girling, 1985). Samples 18, 14, 13 and 1 contained charcoal.

Figure 10.1 illustrates the insect fossil diagram, together with faunal assemblage zones and dates. Table 10.2 shows the classification assigned to each species. To facilitate interpretation of the insect assemblage, the fossil insect diagram is divided into 4 zones: 1, 2, 3 and 4a & 4b. There is a good correlation between minimum number of individuals (MNI) and number of taxa in each sample.

The lower part of the section, **insect zone 1** (340-335cm, sample 20) is poor in insect material, with 41 MNI, across at least 32 taxa. This faunal zone originated from the basal riverine sand and gravel deposits. Although this zone is represented by just one sample, it contains a different range of species compared with successive samples. This zone is characterised by a poor representation of beetles associated with woodland, some wetland species, as well as a small range of hygrophilous and aquatic beetles.

Insect zone 2 (335-285 cm, samples 19-14) contains the richest assemblage, with 1033 MNI, across a minimum of 153 taxa. The samples came from well-humified fen peat, containing wood fragments of *Betula, Salix/Populus, Corylus* (Tyers, *pers. comm.*) and its nuts, *Alnus* seeds and remains of *Phragmites*. Many samples also contained fine-grained sand in lenses within the peat, suggesting that the deposits were subject to periodic or seasonal fluvial deposition (*cf.* Macklin and Needham, 1992). Floodplain fens frequently experience episodic inundation, either directly from the adjoining water courses or because high river water levels help to "pond back" rainwater inputs (Wheeler, 1993). Between 325-315 cm (18) there was abundant charred wood. It is unclear if this material came from a particular horizon (not visible when recording the stratigraphy in the field), or whether it is distributed through this 10 cm sample. Sample 14 (285-275 cm) also contained abundant charcoal and sample 17 contained a fire-cracked sandstone pebble. This zone is characterised by an abundance of tree and wood-dependant taxa, many of which are *Urwaldtier*, as well as species associated with swampy woodland. There are some beetles associated with heath and grassland. Water-margins habitats are also well represented. There is a good range of aquatics, including those found in stagnant and running water.

Insect zone 3 (285-215 cm, samples 13-7) contains a restricted faunal assemblage, with 121 MNI, across 61 taxa. Although samples 13, 12, 10, 9 and 7 were all processed, only two samples were examined: 10 and 7. Sample 7 contained so few individuals (4) that it was excluded from the macrofossil diagram. Both samples scored low on the Preservation Index, although samples 13-12 scored highly. There is a also downward trend in the number of insect fossils recovered, as both samples 13-12 contained a good range of fragments, but this had declined by sample 10 and even further by sample 7. The nature of the faunas also change within sample 10 compared with previously. This part of the sequence (255-245 cm.) appears to mark some sort of change, not only in the nature of the reedswamp/fen adjacent to the river, but also within the wider floodplain landscape. This assemblage zone is characterised by declines in many groups of species, particularly amongst those associated with woodlands, but also wetland species such as those associated with reeds, sedges and aquatics.

Insect zone 4 (215-120 cm, samples 6-1) is divided into sub-zones a and b. Not all samples from this part of the sequence were examined, samples 5, 3 and 1 being the ones selected for further analysis. Sample 5 represents assemblage zone 4a and samples 3 and 1 represent zone 4b. Zone 4a contains a rich faunal assemblage, with 309 MNI, across 122 taxa. Zone 4b contains 166 MNI across 74 taxa. Whereas material for zone 4a originated from fen peat, samples within zone 4b came from alluvium. Zone 4a is characterised by very few species associated with woodland, but an increase in species associated with grassland and herbs and dung and other decaying organic matter. There are also increases in wetland, hygrophilous and aquatic species. In contrast, zone 4b is characterised by a sudden increase in species associated with woodland, but decline in those of open ground. There also a decline in aquatic, wetland and hygrophilous species.

10.2.4 Environmental reconstruction

10.2.4.1 Fossil insect zone 1 (sample 20), c. 4340-4040 cal BC (c. 5340 ±45 BP)

There are few woodland indicators. The NB species *Phyllodrepoidea crenata* is usually found in deciduous woods under bark of dead and dying trees, as well as under lichens and moss on trunks (Koch, 1989). *Anthobium atrocephalum* is found in damp woods, woodland margins and river meadows, in mouldy and fungoid leaves and twigs (Koch, 1989). There are no species dependant on specific tree taxa.

Areas on the banks of the Torne may have been rather sandy and gravelly, grading into aquatic and semi-aquatic vegetation, with areas of plant and flood debris. *Patrobus assimilis* is usually found on rather dry, gravelly or peaty soil (Lindroth, 1974). The NB ground beetle *Trechus rubens* is often recovered on banks of rivers, where it occurs on clayey mull-rich and on peaty soil, usually among leaves and other debris (Lindroth, 1985). The hygrophilous *Bembidion doris* is found in swamps and marshes (Lindroth 1974) as well as in sandy, gravelly or stony places, often with some vegetation, where there is *Carex* spp. and *Eriophorum*, with a distinct moss layer (Lindroth, 1945). *Carpelimus rivularis* prefers muddy banks, where it is found under leaves and debris, especially *Phragmites*, *Carex* spp, and in flood debris (Koch, 1989). This type of habitat would have been suitable for *Cercyon* sp., *Megasternum obscurum* and some of the staphylinids (for example *Lathrobium impressum*; *Oxytelus laequatus*; *Stenus* spp.).

The fossil insects provide little information concerning the nature of the aquatic habitats at this time. There is a small number of aquatic species, but notably none associated with vegetation and detritus-rich aquatic habitats.

10.2.4.2 Fossil insect zone 2 (samples 19-14), c. > 2860-2390 cal BC to 1740-1310 cal BC (3990 ±45 BP to 3145 ±55 BP).

This insect zone is characterised by a very diverse range of families, including Carabidae, Dytiscidae, Hydraenidae, Hydrophilidae, Staphylinidae, Elateridae, Dryopidae, Lathridiidae, Chrysomelidae, Scolytidae and Curculionidae.

10.2.4.2.1 The woodland community

There is a number of Coleoptera that indicate that *Pinus sylvestris* was growing in the vicinity of the Torne floodplain, for example, *Tomicus piniperda. Hylastes opacus* is usually associated with *Pinus*, but can occasionally be found on *Fraxinus excelsior* and *Ulmus* spp (Bullock, 1993). There is also a very good range of pinicolous species that tend to be associated with dead *Pinus*-wood. These include the RDB1 species *Ostoma ferrugineum,* whose larvae feed in the heartwood and sapwood of *Pinus sylvestris* which has been extensively rotted by the fungus *Phaeolus schweinitzii* (Shirt, 1987). *Rhyncolus ater* bores into the dead heartwood of *Pinus* (Alexander, 1994), although on the continent it is also found in deciduous wood (Palm, 1959), as are *Aplocnemus impressus* and *Xyloterus lineatus*. The NB cerambycid *Acanthocinus aedilis* is usually found in old conifer woodland, in the trunks of large fallen *Pinus*, usually soon after the death of the tree (Hunter, 1962; Hyman, 1992).

Other species indicate the presence of a number of deciduous tree taxa. *Hylesinus crenatus* and *Leperisinus varius* are both chiefly associated with *Fraxinus excelsior*, although the former may be found on *Quercus* (Duffy, 1953) and *Tilia* (Koch, 1992). *Quercus* is indicated by its leaf-miner, *Rhynchaenus quercus*. The NB species *Acalles roboris* is usually found in broad-leaved woodland, often in *Quercus* litter. However, on the continent, the species is also associated with *Fagus* (Hyman, 1992). There are no insects that would indicate the presence of this latter tree, although that does not exclude its presence. *Strophosoma melanogrammum* is found mainly on *Betula, Fagus* and *Quercus*, although also occasionally on *Alnus*, *Corylus* and *Pinus* (Phillips, 1992, Bullock, 1993). Areas of *Betula* are at least indicated by its leaf feeder, *Rhynchaenus rusci.* The scolytids *Scolytus rugulosus* and *S. mali* indicate the presence of rosaceous trees and shrubs (Duffy, 1953).

The RDB1 scolytid *Ernoporus caucasicus* appear in three samples, suggesting that *Tilia* was an important component within the landscape during this period. This beetle is found in the drying branches and twigs of the tree (Palm, 1959) and is today restricted to just a few British localities (Shirt, 1987), but is relatively common in fossil insect assemblages of this date (Osborne, 1978; Girling, 1985).

There is also a large range of species that attack dead deciduous wood, such as the NB species *Melasis buprestoides*, which is usually associated with broad-leaved and pasture woodland in *Fagus, Quercus, Betula, Fraxinus* and other deciduous trees (Hyman, 1992). *Cossonus linearis* is often associated with dead *Salix/Populus* (Hickin, 1968), as well as *Pinus* (Hyman, 1992). The non-British *Rhyncolus punctulatus*, NA Melyridae *Aplocnemus nigricornis* and *Dasytes niger* are all found under the bark of decayed wood of various trees (Reitter, 1916; Palm, 1959 Hyman, 1992). A range of other species would have been attracted to the abundant dead wood that must have occupied the floor of the floodplain woodland. The RDB 3 colydiid *Colydium elongatum*, is predatory in the galleries of wood-boring insects (Palm, 1959), for example, on *Grynobius planus*, which was plentiful in these samples, under decayed bark and rotting wood of deciduous and coniferous trees (Horion, 1962). The NA pselaphid *Batrisodes venustus* is found in rotten wood and wood mould, where the adults are probably predatory on mites (Hyman, 1994).

Mould and fungi associated with many of these rotting wood habitats would have attracted a range of species, such as *Cis* spp., which are commonly associated with bracket fungi, and the Lathridiidae *Stephosthetus augusticollis* and *Enicmus brevicornis*. This latter species is common in polypores on *Betula* (Palm, 1959).

The damp, wet habitat in the floodplain area provided a suitable habitat for*Alnus*. This tree is well represented by its beetle, *Chrysomela aenea* and the rare RDB1 species *Agelastica alni,* which is phytophagous on *Alnus* and occasionally on *Corylus* (Hyman, 1992). The damp habitat beneath these trees is represented by a faunal community that includes the hygrophilous *Carabus granularis*, which occurs in stands of *Alnus* along river banks (Lindroth, 1985), *Nebria brevicollis* and its close associate, *Loricera pilicornis* (Lindroth, 1974). These moist habitats would have been ideal for the pselaphids *Bryaxis puncticollis*, *B. curtisi*, *Tychus niger* and the mesophilous forest litter species, *Stenichnus collaris* (Backlund, 1945).

10.2.4.2.2 The heath and grassland communities

This category of habitat is represented by a small number of species that indicate areas of sandy heath within the floodplain catchment. *Calluna* is indicated by its feeders, *Micrelus ericae*, *Lochmaea suturalis* and the heather ladybird, *Chilochorus bipustulatus* (Majerus, 1991). Sandy areas would have been attractive to a range of xerophilous species, such as the ground beetle *Synuchus nivalis* and the scarabaeid *Anomala dubia*, which is often found on coastal sand dunes or inland sandy heaths (Skidmore, *unpubl.*).

Open areas are also indicated by a small range of species such as *Apion* spp., *Phyllotreta* spp., *Sitona* sp. and *Ceutorhynchus* sp. *Hylastinus obscurus* is found on sunny river meadows and heaths and is oligophagous especially on *Trifolium* spp, but can also be found on other herbaceous Leguminosae such as *Medicago sativa* and *Ulex europaeus* (Koch, 1992).

10.2.4.2.3 Wetland and hygrophilous communities

Many species would have been associated with the eutrophic fen adjacent to the river. The RDB 3 *Trechus rivularis* is strongly stenotopic in woodland fens, where there is strong shade from *Betula, Alnus glutinosa* or *Salix* and in vegetation dominated by *Sphagnum* amongst damp *Carex* litter (Lindroth, 1945). It is associated with *Agonum fuliginosum, Pterostichus diligens, P. minor, P. nigrita, Patrobus assimilis, Agonum livens* and *A. obscurum* (Lindroth, 1945). All these species were recovered from the assemblage, apart from the latter two. Although recent records suggest that *T. rivularis* is a distinctly upland species in Britain (Holmes *et al*, 1993; Luff, 1996), at Rossington this beetle occurs in a lowland fen context.

There was extensive waterside vegetation, with abundant aquatic and semi-aquatic habitats represented. *D. versicolorea* is found on *Potamogeton natans*, as well as on other *Potamogeton* spp, *Typha latifolia*, *Sparganium emersum* and *Ranunculus lingua* (Stainforth, 1944). The RDB 3 species *D. aquatica* cocoons on *R. lingua, S. emersum, Glyceria* spp and *Carex* spp. (Stainforth, 1944). The proximity of *Carex* spp. is confirmed by the presence of *Phalacrus caricis* (Bullock, 1993) and the NB reed beetle *P. affinis* (Koch, 1992). *D. impressa* is usually associated with *Schoenoplectus* (*Scirpus*) *lacustris* (Bullock, 1993) and possibly *Carex* spp. (Hyman, 1992). The RDB 2 species *D. bicolora* is associated with *Sparganium erectum* and possibly also *Sagittaria* spp., *Glyceria* spp. and *Carex* spp (Hyman, 1992). *D. vulgaris* is found on *Typha latifolia*, where its cocoons occur on the rhizomes of this and *Schoenoplectus lacustris* (Stainforth, 1944; Bullock, 1993). *Prasocuris phellandrii* is hosted by *Oenanthe* spp. and other aquatic Umbelliferae (Koch, 1992).

The NA reed beetle *Plateumaris braccata* is usually found on *Phragmites australis*, growing in brackish water (Stainforth, 1944), in slow-flowing rivers and estuaries, primarily near the coast (Hyman, 1992). Its presence could be taken to indicate a possible brackish element in the river at this time. However, no other species support such an environmental condition. Moreover, the Continental data on this species makes no reference to any brackish preference (Koch, 1992) and its present distribution may be a reflection of its requirement for good water-quality, rather than any necessity for brackish conditions (P.C. Buckland, *pers. comm.*)

Beneath this abundant vegetation would have been another group of insects, those primarily associated with the *Sphagnum*, plant and reed litter. This group is very well-represented by hydrophilids and staphylinids such as *Cercyon convexiusculus, Megasternum obscurum, Olophrum piceum, O. fuscum, Lesteva heeri* and members of the genus *Lathrobium.*

10.2.4.2.4 The aquatic communities

The aquatic communities fall into two distinct groups: those which are inhabitants of still or slow flowing water and those which are today found in rapidly flowing streams.

Small fen pools or ponded areas adjacent to the Torne would have been suitable for the hydrophilid *Hydraena britteni*, which is found in leaf-rich woodland pools and bog pools, but rarely in streams (Koch, 1989). *H. testacea* also prefers standing waters, covered with pond-weed *Lemna* spp. (Hansen, 1987). Many of the hydraenid and hydrophilid water beetles would have lived in amongst the emergent pool vegetation, such as the ubiquitous *Octhebius minimus*, *Hydrobius fuscipes* and *Anacaena globosus*, all of which prefer vegetation- and detritus-rich waters. The RDB1 Lesser Silver Water beetle *Hydrochara caraboides* is a species typical of lowland fens and clearly favours ponds and stagnant waters with long-established vegetation (Shirt, 1987; Friday, 1988; Guest, 1996). The diverse range of aquatic and semi-aquatic plants would have been made this location particularly suitable for this species.

There are also a range of species characteristic of slower waters, such as the NB hydraenid *Ochthebius bicolon* (Hansen, 1987) and *Hydraena riparia*, which are both taken in both running and stagnant water (Balfour-Browne, 1958). *H. pulchella* is also found in streams with muddy backwaters (Friday, 1988). *Orectochilous villosus* is associated with running water and in wave-washed edges of water (Friday, 1988). Carr (1916) records it as having been taken in abundant quantities on the margins of the river Trent.

In addition to this range of species, aquatic riffle beetles are present. These are generally associated with running water. *Oulimnius tuberculatus* is common under stones in streams and rivers, particularly large rivers with unstable stony beds (Holland, 1972). *Limnius volckmari* is found in clean rivers and streams, under stones (Holland, 1972) and the NB species *Riolus subviolaceus* is found in base-rich running water (Friday, 1988). The curious juxtaposition of stagnant/slow moving waters and running water aquatics is discussed further in section 10.5.7.

10.2.4.2.5 The decay community

This community is dominated by beetles associated with all types of decaying matter, although there are also some exclusively associated with herbivore dung. Within this first group are *Cryptopleurum minutum* and *Onthophilus striatus* which are found in all kinds of decaying organic matter, often among various plant debris near water, as well as in dung and at carrion (Harde, 1984; Hansen, 1987). *Anotylus rugosus* is relatively abundant and is found in rotting vegetation as well as in dung of cattle and humans (Koch, 1989). The presence of low-levels of animal dung is indicated by the dung beetles of the genus *Aphodius* and *Geotrupes stercorarius*. This latter species appears to favour cow and horse (Davis, 1980) and more rarely sheep dung (Koch, 1989).

10.2.4.3 Fossil insect zone 3 (samples 10-7), c. 1740-1310 cal BC to > 1690-1450 cal BC

This insect zone is characterised by a restricted range of families dominated by the Carabidae, Hydraenidae, Staphylinidae and Chrysomelidae.

10.2.4.3.1 The woodland community

This community is represented by few individuals. The scolytids, *Tomicus piniperda* and *Pityogenes* sp. indicate that their host, *Pinus sylvestris*, continued growing in the area. The RDB 1 scolytid *Ernoporus caucasicus*, indicates the continued presence of *Tilia*, although this species disappears after this point. *Alnus* continues to be an important component of the vegetation on the fen adjacent to the river channel, indicated by the chrysomelids *Chrysomela aenea* and the RDB 1 *Agelastica alni*. It is notable that the range of rotting-wood species is not well-represented in this period, as previously. Few of the species, for instance, are typical of undisturbed woodland, with the exception of possibly the NA Melyridae *Dasytes niger*, which is found under the bark of decayed wood of various deciduous and coniferous trees, apparently predaceous on the larvae of Diptera (Palm, 1959; Buckland, 1979).

10.2.4.3.2 The heath and grass communities

This faunal community is represented by just a couple of species. *Lochmaea suturalis* suggests *Calluna vulgaris* continued growing in the area. *Polygonum* and *Rumex* spp. are indicated by the chrysomelid *Chaetocnema concinna* (Bullock, 1993).

10.2.4.3.3 Wetland and hygrophilous communities

The littoral zone of the swampy-backwater continued to be inhabited by a range of ground beetles, such as the RDB 3 fen woodland species *Trechus rivularis* and *Pterostichus diligens*. The hygrophilous *Agonum thoreyi* occurs at the margin of standing waters or in marshes, where the soil is soft and rich in organic matter, with dense vegetation of *Phragmites*, *Typha Carex* (Lindroth, 1966, 1974). *Psammoecus bipunctatus* is often recovered at the margins of water in reed debris (Reitter, 1911), often in the stems of *Typha* and *Phragmites*, as well as in *Carex* and *Juncus* tussocks (Koch, 1989). The proximity of *Carex* spp. is confirmed by the presence of the NB reed beetle *Plateumaris affinis* (Koch, 1992). The RDB 3 species *D. aquatica* cocoons on *Ranunculus lingua*, *Sparganium emersum*, *Glyceria* spp and *Carex* spp. (Stainforth, 1944), whereas *D. simplex* is oligophagous on *Glyceria* spp., *Carex* spp., *Sparganium* spp. and *Typha* spp. Vegetation such as *Oenanthe* spp. and other aquatic Umbelliferae are indicated by *Prasocuris phellandrii* (Koch, 1992) and there were probably areas covered with *Lemna* spp., the host of *Tanysphyrus lemnae*. Beneath the plant litter was a community of staphylinidae (e.g. *Olophrum fuscum*, *Lesteva heeri*, *Stenus* spp.).

10.2.4.3.4 The aquatic communities

This zone contained a relatively restricted assemblage of aquatic insects. Many of the hydrophilids in the preceeding samples are not present, except the common *Ochthebius minimus*. This small hydraenid is found in all types of water, often in detritus-rich conditions (Friday, 1988; Hansen, 1987).

There are no species associated with slowly moving, and few associated with running water. The range of riffle beetles in the previous assemblage zone is not displayed, although the NA elmid, *Oulimnius rivularis* is present, a species found in fen drains (Friday, 1988). *Limnebius truncatellus/papposus* is likely to indicate some running water, since both beetles are found in streams and rivers (Balfour-Browne, 1958).

10.2.4.3.5 The decay community

This community includes the dung beetle *Aphodius prodromus*, which is eurytopic, highly polyphagous, feeding on all kinds of dung, although it can also be found in compost and among decaying vegetables (Landin, 1961). *Anotylus rugosus* is found in rotting vegetation, as well as in dung (Koch, 1989). There are also ranges of eurytopic species that are associated with many types of rotting animal and plant matter (e.g. *Cercyon* spp., Aleocharinae).

10.2.4.4 Fossil insect zone 4 (samples 5-1), c. > 1690-1450 cal BC to 130-400 cal AD (4a: c. > 1690-1450 cal BC to 410-190 cal BC and 4b: c. 410-190 cal BC to 130-400 cal AD)

This insect zone is divided into two sub-periods. Zone 4a is dominated by members of the Carabidae, Dytiscidae, Hydraenidae, Hydrophilidae, Hydrophilidae, Staphylinidae Scarabaeidae, Chrysomelidae and Curculionidae. Zone 4b is characterised by members of Dytiscidae, Hydrophilidae, Staphylinidae, Chrysomelidae and Curculionidae.

10.2.4.4.1 The woodland community

During zone 4a there are few species associated with trees, apart from *Rhamphus pulicarius*, which lives on *Salix*, *Populus*, *Myrica* and *Betula* spp. (Morris, 1993). Other species may have been associated with damp woodland. Members of the genus *Dorytomus* are generally found on wetland trees, such as *Salix* and *Populus*. The carabid *Loricera pilicornis* shows a clear preference for shaded deciduous forest in undisturbed localities (den Boer, 1977), but can also be characteristic of intensively managed grassland pastures (Eyre and Luff, 1990).

In contrast, there is a large increase in species associated with woodland during zone 4b. However, most of these beetles are rather generalist, associated with all types of woodland. *Xyleborus saxeseni* is found in most broad-leaved trees, often also in fruit trees and singly in coniferous trees (Lekander *et al.*, 1977; Koch, 1992), whereas members of the leaf-miners *Rhynchaenus* are found on all types of deciduous trees. The flightless *Strophosoma melanogrammum* feeds on various deciduous trees and conifers, although the larvae live on roots of *Rumex* and other herbaceous plants (Harde, 1984). It can often be found on *Corylus avellana* (Bullock, 1993). There is one species associated with a particular tree: *Hylesinus oleiperda* is usually found on *Fraxinus excelsior* (Bullock, 1993). There are no species associated with *Alnus* carr, although *Alnus*-wood was found in the stratigraphy at this point.

10.2.4.4.2 The heath and grass communities

There are a high number of species associated with open heath and grassland during zone 4a. *Lochmaea suturalis* and *Micrelus ericae* indicate the continued presence of *Calluna*. There are also several xerophilous species, such as *Byrrhus pilula* (Backlund, 1945) and *Anomala dubia*, which is often found on coastal sand dunes or, more rarely, inland sandy heaths (Skidmore, *unpubl*).

There are a range of species associated with herbs and grassland, such as the chafer *Phyllopertha horticola*, whose larvae are pests on roots of grass and clover in meadows (Horion, 1959). Other beetles are associated with a variety of waste, cultivated and open ground plants. *Rhinoncus bruchoides* is found on *Persicaria maculosa* and other weeds species (Morris, 1991; Bullock, 1993). *Polygonum* and *Rumex* species are usually the hosts of *Chaetocnema concinna* (Bullock, 1993). *Ceutorhynchus contractus* is found on various Brassicaceae, including cultivated varieties (Lindroth *et al.*, 1973).

In zone 4b, however, there is a much-restricted range of species in this category. *Xantholinus linearis* could indicate the continued presence of *Calluna* heath (Richards, 1926), although it could have been living on sandy margins of the river. The ladybird *Rhizobius litura* is commonly associated with grasslands, meadows and low-growing herbaceous plants (Majerus *et al.* 1997).

10.2.4.4.3 Wetland and hygrophilous communities

During the earlier period, there continues to be a diverse range of ground beetles living on the fen adjacent to the river, such as the RDB 3 *Trechus rivularis*, *Pterostichus diligens*, *P. nigrita/rhaeticus*, *P. minor* and *Elaphrus cupreus*. The NB species *Agonum versutum* is found at the margins of water, where it is predatory amongst lush vegetation of *Typha*, *Carex* and mosses (Lindroth, 1974; Hyman, 1992).

A diverse range of aquatic and semi-aquatic vegetation is indicated by the reed beetles, such as the NB species *Donacia crassipes*, *D. versicolorea*, NA species *D. obscura*, *D. simplex* and *Plateumaris sericea*. These indicate the presence of plants such as *Nymphaea alba* and *Nuphar lutea*; *Potamogeton natans*, *Potamogeton* spp., *Glyceria* spp., *Typha latifolia*, *Typha* spp., *Sparganium emersum*, *Sparganium* spp. and *Ranunculus lingua*, *Carex rostrata* and other *Carex* spp. (Stainforth, 1944; Hyman, 1992). The ladybirds *Coccidula scutellata* and *Anisosticta novemdecimpunctata* are found in wetlands, especially on *Typha* spp. and *Phragmites* spp. (Majerus, 1991; Bullock, 1993; Majerus *et al.*, 1997). Water milfoil, *Myriophyllum* spp. is indicated by its phytophagous NB weevil *Eubrychius velutus* (Hyman, 1992). *Prasocuris phellandrii* indicates its host, *Oenanthe* spp. (Koch, 1992).

In contrast to this rich assemblage, zone 4b is impoverished of its waterside vegetation fauna, although there are some associated species. The ladybird *Anistosticta novemdecimpunctata* indicates the continued presence of *Typha* spp. and *Phragmites* spp. *Donacia clavipes* indicates *Phragmites australis* and *Sparganium* spp. (Hyman 1992), plants which *D. cinerea* also feeds upon (Hyman, 1992). The RDB 3 *D. aquatica* and *D. simplex* are phytophagous on *Ranunculus lingua*, *Sparganium emersum*, *Glyceria*, *Carex* and *Typha* spp (Stainforth, 1944). *D. marginata* is monophagous on *Sparganium erectum* (Koch, 1992). *Myriophyllum* and *Oenanthe* spp. continue to be present. However, the previously diverse fen ground beetle population is no longer evident. Many of the species that would have been associated with the damp, rotting plant litter beneath the plants is also reduced.

10.2.4.4.4 The aquatic communities

During the early part of this zone, there is a particularly rich hydrophilid fauna, many of which are typical of rich mesotrophic lowland ponds and fen drains, (e.g. *Hydrochus elongatus*; *Helochares punctatus;* RDB 3 species *H. obscurus; Chaetarthia seminulum*). The detritus-rich *Sphagnum* pools would have been suitable for the RDB 3 hydrophilid *Limnebius aluta, Ochthebius minimus, Helophrus brevipalpis, Hygrotus inaequalis* and *Hyphydrus ovatus.* The RDB 1 lesser silver water beetle *Hydrochara caraboides* is characteristic of such lowland fens with diverse emergent vegetation (Shirt, 1987).

This evidence suggests stagnant, detritus-rich areas on the fen, and there is a notable paucity of flowing water species. *Gyrinus aeratus* is typical of calm embayments of streams and rivers, although it can also be found on ponds (Koch, 1989). *Oreodytes septentrionalis* and the NB hydraenid *Hydraena nigrita* are often most abundant in sandy-gravelly pools (Koch, 1989; Nilsson and Holmen, 1995). *Limnebius truncatellus/papposus* are frequent in streams and amongst vegetation at the margins of rivers (Balfour-Browne, 1958).

In Zone 4b, in contrast, there is an impoverished aquatic fauna and many species are generalists. The detritus-rich fen species *Limnebius aluta* is still present, as well as the ubiquitous *Ochthebius minimus. Graptodytes pictus* is typical of vegetation-rich standing waters (Koch, 1989). There are very few species of running water, apart from one riffle beetle, *Limnius volkmari,* which occurs in clean rivers and streams (Skidmore, *unpubl.*).

10.2.4.4.5 The decay community

This is an important community in zone 4a, with dung beetles being particularly well-represented. These include *Aphodius fossor, A. sphacelatus* and *A. prodromus.* Whilst the former is usually found in cow dung (Landin, 1961), the latter two are usually found together in dung of animals and vegetable matter (Jessop, 1986). A range of other species may have been living on either dung or decaying vegetable matter, such as *Cryptopleurum minutum, Anotylus rugosus* and *Aphodius granarius.* It is likely that this fauna reflects the presence of grazing animals on the Torne floodplain.

Zone 4b reflects the continued presence of dung-indicating species. There is one interesting species, *Heptaulacus testudinarius*, a beetle which is often recovered from manured fields as well as decaying haystacks (Landin, 1961). This species seems to appear first in the fossil record during the Iron Age and is associated with faunas from the Roman and post-Roman periods. The appearance of this species in fossil deposits may be linked to the onset of more widespread farming initiated during the Iron Age.

10.2.5 Diversity indices

Figure 10.2 illustrates the diversity values obtained for the Rossington faunas. The graph indicates great faunal diversity in the period represented by the lower samples, particularly those within assemblage zone 2, dated between 2860-2390 cal BC and 1740-1310 cal BC. The very high diversity values reflect the rich aquatic and semi-aquatic habitats, as well as the abundance of insects inhabiting *Urwald* woodland. However, declining diversity is evident from sample 14 onwards and reflects the decline in specialised insect habitats and heralds the onset of human impact in the Torne catchment.

10.2.6 Species of note

Although only one non-British species (*Rhyncolus punctulatus*) has been recovered from the deposits at Hayfield Lodge Farm, there is an abundance and diversity of species which are today very rare or restricted in their distribution. These include five RDB 1, four RDB 2 and five RDB 3 species, as well as ten NA and twenty-five NB species.

10.3 Taphonomic considerations

It is worth discussing some of the local and non-local components of the faunas. There is very little evidence to suggest that any of the fossil material had been eroded through riverine transport, indicating that most of the assemblage was autochthonous rather than allochthonous. It is important to consider how good a representation a floodplain succession provides of its surroundings. Very little research has been carried out on floodplain faunas, although work by Dinnin and Brayshay (*in press*) suggests that there can be a very good correlation between pollen and insect data. The assemblage from Rossington shares many similarities with this research from Bole Ings (Nottinghamshire). Kenward (1978) carried out modern taphonomic work on faunas from stream deposits, and found that modern samples showed a moderately good indication of the surroundings. However, he noted that the fauna recovered can be affected by where it is in the river catchment and noted that the further downstream, the greater the mixture of species. In some samples, for instance, he noted that just a single woodland species was recovered, although the woodland edge was only 10 m away. He also noted that there were few beetles associated with dung, even though cows grazed within a few metres of the edge of stream. Roper also noted the low number of dung beetles when trapping insects in areas which were being used as animal pasture (Roper, *pers. comm.*). This could mean that that the presence of grazing herbivores may be consistently under-estimated in certain deposits.

Robinson (1983) discusses some of the problems associated with identifying arable/pastoral ratios from insects and suggests that beetles from the genera *Geotrupes*, *Colobopterus*, *Aphodius* and *Othophagus* are good indicators of grazed grassland. He points out that they cannot be used to obtain arable/pastoral ratios but can highlight the importance of pasture-land, particularly when the data is viewed comparatively with other samples. This means that samples which show an increase in these elements are likely to reflect a change in land-use, even though the range of species and numbers involved may be modest, as they are in the succession at Hayfield Lodge Farm.

10.4 Environmental interpretation and correlation with palynological evidence

10.4.1 Stratigraphic evidence

In the mid-Holocene, once the deeply incised river channels had infilled, many of the rivers of the Humberhead Levels adopted a meandering course across the floodplain. This causes migration of channels, resulting in episodes of channel abandonment and the formation of extensive wetland areas alongside the rivers and their floodplains. It is from one of these extensive floodplain wetlands that the Rossington sequence originates.

The stratigraphy indicates that development of fen carr in this area probably occurred in a relatively low energy backswamp environment during a period of relative floodplain stability (Mather, 1991). The environment would have been peripheral to the main channel of the Torne, although layers of sand and silt (alluvium) indicate that the backswamp must have been subject to periodic, variable intensity, flooding. Mather (1991) attributed evidence for phases of coarse sand deposition to human-activity destabilising soils upriver, but Dinnin (1997d) points out that the river cuts through the Rossington Ridge which is flanked by relatively steep sand and gravel slopes. Bank erosion at the base of these deposits would have destabilised the sediments, providing the river with episodic coarse sediment. Downstream at Wroot, there is an absence of such coarse-grained sediments (Dinnin, 1997d).

The alluvium sealing the fen peat deposits at the top of the sequence, succeeded by the coarse sand deposits above, indicates a major environmental change within the Torne catchment, followed by a period of instability.

10.4.2 Period 4340-4040 cal BC and later

The base of the sequence, dated to 4340-4040 cal BC (covering the late Mesolithic), provides little information regarding the nature of the landscape at this time. Figure 10.3 attempts to correlate the palynological with the fossil sequence. Figures 10.4a, b show Mather's (1991) pollen diagram. It is apparent that the base of the Rossington sequence is roughly contemporaneous with the latter part of Mather's zone HLF 2a. The pollen of *Pinus*, *Alnus* and *Corylus* are dominant during this period, with *Quercus*, *Ulmus* and *Tilia* also important, possibly indicating the establishment of fen-carr woodland in the floodplain. However, none of this woodland is indicated by the fossil insect faunas, which may provide just a very immediate picture of the environment. Kenward's (1978) comments concerning woodland faunas may be appropriate here (see section 10.4). There are several species which suggest that the area adjacent to the river was poorly vegetated and the samples may represent a fauna which was living on sandy, exposed areas next to the Torne, perhaps where a sand or gravel bar had formed. The characteristic vegetation and detritus-rich habitats evident within the succeeding samples is not present, suggesting that fen habitats had not developed at this time in this particular area of the floodplain.

Mather (1991) detected a charcoal horizon towards the top of his zone HLF2a, the second of this part of the sequence. He had also noted an obvious charcoal horizon at the base of his sequence, in his zone HLF 1, a period characterised by *Pinus*, *Betula* and *Salix*. These two horizons were interpreted as representing two possible episodes of burning prior to an *Ulmus* decline, which he suggested was the result of human activities on the sandy soils of the higher ground adjacent to the Torne. Neither of these charcoal horizons were noted from the palaeoentomological sequence, although charcoal was noted further up the profile.

There is a large disparity between the basal date 4340-4040 cal BC and the next date obtained (2860-2390 cal BC), although this latter date was obtained just 15 cm above the base. It is unlikely that *c.* 1500 years of peat deposition is represented in just 15 cm of deposit, so this would suggest that there was a hiatus in detrital peat deposition sometime during this period, presumably during a period of lower river water levels. Floodplains can be characterised by frequent disturbances which can provide hiatuses in the palaeoecological record (Brown, A.G., 1997). The date was obtained from wood at the base of the sequence, at 340 cm, whereas sample 20 originated from 340-335 cm, so it is possible that the wood was not contemporaneous with the peat's contents. However, given the very different nature of the samples' contents compared with successive samples, it seems more likely that the fossil insects are at least partially contemporaneous with the dating material and that peat accumulation in this area did not commence in a sustained manner until shortly before 2860-2390 cal BC. This period corresponds closely with peat initiation on the raised mires and detrital peat deposition in the channel of the old river Don, at *c.* 3020-2620 cal BC (4230 ± 100 B.P, BIRM-358) (Buckland, 1979) and in the old River Idle, at *c.* 3300-2700 cal BC (4300 ± 100 BP, BIRM-359) (Buckland and Dolby, 1973).

10.4.3 Period 2860-2390 cal BC to 1740-1310 cal BC

Assemblage zone 2 covers parts of the Neolithic and Bronze age. The faunas are very different to the previous period, being characterised by many species typical of *Urwald* woodland. *Pinus*, *Fraxinus*, *Quercus*, *Betula*, *Alnus* and *Tilia* are all clearly important trees. *Corylus* is also an element in this landscape, indicated by its nuts being incorporated within the fen peats. Unfortunately, this tree is not associated with many beetle species. Undisturbed woodland appears to have persisted in the vicinity for the period represented by the assemblage, with many species indicating long-lived, mature woodland.

On the fen carr itself, *Alnus* is likely to have been growing, together with stands of *Betula* and *Salix*. A rich faunal community lived beneath the mesophilous litter layer. A wide variety of marsh and aquatic plants lived in the vicinity, such as *Phragmites australis*, *Carex*, *Typha latifolia*, *Typha* spp., *Potamogeton natans*, *Sparganium emersum*, *S. erectum*, *Ranunculus lingua*, *Glyceria* spp., *Sagittaria* spp., *Schoenoplectus lacustris* as well as areas of *Sphagnum*. These plants probably lived adjacent to wet and detritus-rich pooled areas on the fen, where a varied fen aquatic fauna lived. Some of these pools may have been substantial and could have formed seasonal meres. Slowly moving streams probably moved across the fen, where another range of species lived. The floodplain was probably maintained by a high water-table.

There are indications of possible background levels of human activity. For instance, the presence of herbivores is clearly indicated within this period, illustrated by small numbers of beetles associated with dung. These beetles could have been incorporated into deposits as a result of animals visiting areas adjacent to the river for water or could reflect background levels of animals being pastured in the area of the floodplain. It is possible that the backswamp area near the Torne may have been used as grazed marsh, grading into wet pasture.

This period is analogous with most of Mather's (1991) zone HLF 2/b, *Alnus-Quercus-Corylus* zone. The most significant aspect of this zone is the *Ulmus* decline at the start of the subzone and the disappearance of *Tilia* in the uppermost level. *Fraxinus* and *Fagus* also make their appearance in this period. The period following the *Ulmus* decline is characterised by declines in levels of *Populus*, *Betula* and *Quercus* and the elimination of *Pinus* and *Fraxinus* from the reminder of the subzone. Mather also notes evidence of possible pastoral agriculture and suggests that anthropogenic impact on the landscape is greater here than elsewhere in the Humberhead Levels (*cf.* Smith, 1985).

The insect evidence complements some of the palynological evidence and adds further details about the landscape at this time. For instance, although Mather thought *Pinus* disappears during this period, the insect evidence suggests that there are low-levels of invertebrate species associated with this tree throughout the period. Beetles associated with heath indicate that this habitat was also important, perhaps on the sandy uplands beyond the floodplain; *Pinus* is likely to have favoured these sandier soils.

10.4.4 Period c. 1740-1310 cal BC to > 1690-1450 cal BC

The fossil insect evidence for this period suggests that there had been a dramatic decline in the extent of woodland or in woodland habitats by 1690-1450 cal BC (3290 ± 45 BP, SRR-6131). The insect species illustrate that *Pinus* and *Alnus* are still important components of this landscape. There are virtually no species of undisturbed woodland.

The insect evidence indicates that *Tilia* was present in the landscape from before *c.* 2860-2390 cal BC (3990 ± 45 BP, SRR-6135) but seems to disappear from the record during this period, sometime after *c.* 1690-1450 cal BC (3290 ± 45 BP, SRR-6131). This date is roughly analogous with Mather's *Tilia* decline, dated to *c.* 1200-1300 cal BC and overlaps with Turner's (1962) primary *Tilia* decline at Thorne Moors dated to 1750-1100 cal BC (3170 ± 115 BP, Q-482). This decline seems to mark a notable change in the landscape and by the Bronze age, much of the area of the river Torne floodplain seems to have been cleared of primary woodland, although patches of woodland probably remained. This impression is corroborated by a small background fauna of dung beetles.

There continue to be a good range of species associated with water-side plants, suggesting dense vegetation of *Phragmites, Typha* spp., *Carex* spp., *Ranunculus lingua, Sparganium simplex, Glyceria* spp., *Oenanthe* spp., and pools covered with *Lemna* spp. It is notable, however, that the range of aquatic species evident previously is not present, including the detritus-rich and running water categories. The elmids, for instance, were probably adversely affected by poor water-quality and their absence could suggest that greater amounts of silt were becoming incorporated within the floodplain system. The low diversity of species associated with detritus habitats also suggests environmental change within the river system. It is possible that their lack of diversity may have in response to higher amounts of river pollution and silt deposition.

This fossil insect zone overlaps with the end of Mather's zone HLF 2/b and HLF 2/c and broadly concurs with this evidence. Mather suggests that this period is characterised by two phases of clearance which he believed occurs in the later Bronze age and the earlier Iron age. The trees most affected by the clearance are *Ulmus* and *Tilia* and this is, to a certain extent, reflected by the insect data. The fen-carr community in the floodplain, he suggests, is represented by the undiminished levels of *Alnus* and possibly *Quercus*. He also suggests that there appears to be a greater emphasis on pastoral agriculture, although there may have been some local arable cultivation. Such expansions in agricultural activity are also evident in Smith's (1985) pollen diagrams from the Moors and suggests that major regional deforestation and agricultural activity did not occur until late in the Bronze age and into the Iron age.

10.4.5 Period c. >1690-1450 cal BC to 130-400 cal AD

During the early part of this period, zone 4a, (> 1690-1450 cal BC to 410-190 cal AD) the woodland element in the assemblages is very minor and there are indicators of open ground and evidence of grazing animals. This period is analogous with the early part of Mather's HLF3 zone. The beginning of this pollen zone is marked by an almost complete reduction of tree cover, which includes reduced values of *Alnus.* Mather (1991) suggests that the reduction in arboreal taxa may, in part, be due to increased levels of wetness in the floodplain, causing the demise of trees in this area. This suggestion is supported by the palaeoentomological evidence, which shows an increase in aquatic and hygrophilous species during this period, including the larger water beetles, which require more permanent and extensive pools. There is also a very rich aquatic-vegetation fauna, supporting the impression of larger areas of wetland habitat. Woodland taxa may also have declined in response to increasing levels of wetness.

Mather found evidence for widespread forest clearance during the late Iron age and early Roman period, suggesting that *Tilia, Ulmus* and *Pinus* decreased, possibly as a result of clearance activities. The insect evidence adds to this evidence and indicates areas of meadow and a variety of species which are often associated with waste, cultivated and open ground.

However, during the latter part of the zone (4b) (*c.* 410-190 cal BC to 130-400 cal BC), there are large increases in species associated with woodland, although many species are generalists, and none are associated with old woodland habitats. This increase could be associated with regeneration of local woodland and indicates the lack of late successional habitats within such woodland. It is not possible to be sure which trees are represented, although *Fraxinus* appears to have been present, as well as other deciduous trees, possibly *Corylus*, although this is difficult to substantiate. *Alnus* is also still present, indicated by its wood in the stratigraphy. Mather (1991) detects changes in his pollen evidence at this time, with increases in the representation of *Corylus* and to a lesser extent of *Alnus, Betula, Fraxinus* and *Quercus.* He also notes high representations of macroscopic charcoal. Mather (1991) tentatively correlates the combination of high charcoal and the increase in arboreal taxa with the supplying of the Roman kiln sites, *c.* 450 metres upstream from his site, with locally produced coppiced wood. Management of woodlands seems to have been practised from the Neolithic period onwards, with evidence for coppicing (Rackham, 1986) and pollarding (Rasmussen, 1990). Evidence for coppiced wood associated with Roman industrial activity suggests that the use of wood from managed woodland was common (e.g. Fulford and Allen, 1992)

The increase in beetle species associated with woodland could corroborate Mather's suggestion. The evidence could indicate that areas of woodland were being regenerated, although it not possible to say whether it was being managed or coppiced/pollarded. Species such as *Corylus, Alnus, Salix* and *Quercus* can all be used for such a purpose. However, its worth noting that the insect evidence covers a considerable time period (410-190 cal BC to 130-400 cal AD) and would indicate evidence for an upward trend of woodland regeneration over the whole period, rather than a relatively limited period over *c.* 140-370 AD, when the kilns were active (Buckland *et al., in press*). In addition, aquatic insects show a decline during this period and expansion of the floodplain woodland may have been as a result of a drying of the fen after a previously wet period. The relationship between wood-loving species and aquatics shown in Figure 10.1 clearly indicates that there is direct relationship between these two categories and that the expansion and contraction of tree species appears to have been in response to lower/higher water levels. The increase in aquatics evident right at the top of the diagram, together with the rapid decrease in woodland taxa would support this hypothesis.

There is thus some evidence to indicate that the floodplain was becoming increasingly waterlogged during this period, with a resurgence of high water levels at the top of the profile, dated to 130-400 cal AD, sometime in the Roman period. Evidence from elsewhere in the Humberhead Levels supports the idea of increasing water levels during this period (e.g. Buckland and Sadler, 1985). The deposition of alluvium at the top of the peat sequence provides stratigraphic evidence for flooding of the floodplain and of erosion of soils upstream. Indeed, evidence for flooding and erosion is evident from the kiln sites at Rossington (Buckland *et al, in press*), virtually opposite the palaeoentomological site.

At Sandtoft, close to the confluence of the Don and Idle (of which the Torne is tributary) flooding was an increasing problem during the latter part of the Roman occupation of the site (Samuels and Buckland, 1978). Recent work at Littleborough, on the River Trent, suggests similar evidence for late second century AD or early third century flooding (Riley *et al.*, 1997). Dinnin (1997e) points out that similar alluvium at Bole Ings on the River Trent may be related to the same event. Similar destabilisation events are known from other sites in Britain (e.g. Kelly and Osborne, 1965) and vary in date from area to area, in accordance with soil type, vegetation and degree of landscape use. For instance, Shotton (1978) observed destabilisation in the Warwickshire Avon during the Bronze age. Robinson notes that in the upper Thames floodplain in Oxfordshire, alluviation appears to have begun some time towards the end of the Iron age and terminated sometime around the 4th century AD (Robinson, 1981b, 1992a).

In the Humberhead Levels, destabilisation appears to have occurred within the Roman period. The mechanisms behind the causes of alluviation in the Humberhead Levels are discussed further in the next Chapter (section 11.6).

10.4.6 The significance of charcoal within the samples

Mather (1991) identified two pre-*Ulmus* decline charcoal bands within the stratigraphy at Hayfield Lodge Farm, together with three other charcoal bands. The high frequencies of charcoal, together with fluctuations in *Pinus*, *Betula* and *Corylus* led Mather to suggest Mesolithic exploitation of the woodland using fire (*cf.* Mellars, 1976). However, little consideration was given to the possibility of natural fires within a *Pinus*-dominated landscape (Dinnin, 1997a) or to the appropriateness of using ethnographic analogies based on American and Australian traditions of burning landscapes (ecologically very different to British ones) to attract game animals (*cf.* Mellars, 1976), in the context of a lowland floodplain and fen landscape.

This study identified the presence of charcoal in several samples, namely between 325-315 cm (sample 18), 285-275 (samples 14 and 13) and occasional charcoal within the alluvial deposits at the top of the profile (sample 1) and suggests that fire was a relatively regular feature of the floodplain landscape.

The charcoal noted at 325-315 cm is not contemporaneous with any of Mather's charcoal bands. The amount of charred wood within sample 18 could indicate *in situ* burning on the fen. Cowell and Innes (1994) suggest that deliberate burning of reedswamp vegetation was carried out in prehistory to attract game to an area for hunting and that the wet nature of reed swamp makes them unlikely to burn naturally. The Coleopteran evidence suggests that such environments would have contained abundant dead plant litter which would have provided a ready supply of combustible material, particularly during periods of seasonal dryness and does not necessarily suggest human firing of the reedswamp.

The charcoal evidence from the rest of the profile could indicate material being washed onto the fen from the river or down-slope from the surrounding areas. It is possible that such material may have originated from human activities (particularly the charcoal from the top of the profile, which would have been more-or-less contemporaneous with the pottery industry at Rossington, on the opposite bank of the Torne). However, it is important to consider that within the surrounding *Betula-Pinus* natural forest fires need not have been infrequent and that anthropogenic explanations of fire and the occurrence of charcoal are not always necessary.

10.4.7 The significance of the mixture of aquatics within the samples

The curious juxtaposition of stagnant/slow moving waters and running water aquatics within some of the samples requires some consideration.

It is possible that riffle beetles may have been incorporated within the deposits through periodic flooding episodes. If these aquatics were transported to the site through flooding, this is not evident from differential preservation levels across the assemblage and none of the fossils show any particular signs of abrasion. It is possible that water may have periodically flowed over the fen from the river allowing some of the species associated with running water to become incorporated within the peat deposits or that they were actually living adjacent to the detritus-rich waters, perhaps on the margins of the flowing river.

Osborne (1988) discusses this problem in a paper regarding a similar riverine assemblage from the Warwickshire River Avon, where there was also a mixture of running water and stagnant-water species. In the past, this mixture of aquatics has been attributed to flooding episodes. However, work carried out by Shotton and Osborne (1965) suggests that elmids are unlikely to have become incorporated into flooding debris. The faunas from Rossington also suggest that the insects had not become incorporated within deposits due to flooding because of the preservation of the fossils. Osborne (1988) suggests that in the past both assemblages of beetles would have co-existed in the same environment and the disappearance of elmids from quieter waters may be due to anthropogenic influences upon river systems. These beetles like clean river bottoms where they cling to stones; the blankets of mud and silt, which have built in slow-moving rivers is likely to have restricted these aquatics to cleaner environments, such as rapidly moving rivers and unpolluted lochs. The evidence from Hayfield Lodge Farm lends further support to Osborne's arguments and suggests that the river Torne during this earlier period was relatively unpolluted of silt and would lend further support to the idea that the landscape was relatively uncleared at this time. It is pertinent to note that the Elmids disappear further up the sequence, about *c.* 1740-1520 cal BC (3330 ± 45 BP, SRR-6133), which may have been in response to greater silt loads being incorporated into the river as a result of human activity up-river.

10.5 Misterton Carr

Misterton Carr, Nottinghamshire, is located *c.* 15 km south of Hatfield, on the River Idle floodplain. The floodplain was investigated as part of excavations of a series of three Mesolithic and later flint scatters in the vicinity of Misterton Carr Farm (Buckland and Dolby, 1973; Gringley-4 and -5 of Head *et al.*, 1997b) (Figure 4.5 a & b). The flint scatters were exposed on Late Glacial wind-blown sands (the "Cover Sands") due to improved drainage, which had caused desiccation of the overlying peat (Buckland and Dolby, 1973). The scatters were distributed alongside the pre-1620s channel of the River Idle. The Misterton artefacts constitute the largest assemblage recorded from north Nottinghamshire (Buckland and Dolby, 1973). Further areas of these scatters have been recently recorded (Head *et al.*, 1997b). The evidence suggests that the river Idle has been the focus for exploitation from the Early Mesolithic through to later prehistory (Head *et al.*, 1997b). Recent pottery scatters of late third and early forth century AD date have been identified in the vicinity of the Misterton Carr site (Gringley-13 of Head *et al*, 1997b) and a number of crop marks have been identified, representing regular fields of possible Roman date (Chapman, 1997). There are also extensive collections of Roman finds made by metal detector users in the area (Dolby, *pers. comm.*).

10.5.1 The palaeoentomological samples

The palaeoentomological evidence from Misterton Carr was first examined by Peter Osborne in the 1970s. A brief account of the assemblage was published, but work at this stage was still preliminary (Osborne, 1978). The following account is therefore based upon the data provided by Osborne to the author. Although it was first hoped to complete the examination of the assemblage during this research, the degraded nature of the material made any further identification work impossible. Table 10.3 lists the fossil insects recorded from Misterton.

Although six samples had been identified in their entirety (samples 37-33 and 21), representing 253 MNI, across at least 63 species from 22 families of Coleoptera, other samples (30, 27, 25, 20, 18, 15, 14, 13, 11, 2) provide incomplete lists of species, with no quantification. These samples are included in Table 10.3, but are recorded on a presence/absence basis only. Because of the incomplete nature of the assemblages and the low and fluctuating number of individuals represented in the identified samples, it was decided not to categorise the data using the ecological classification system or display the results using TILIA.

The following account attempts to broadly summarise the environmental evidence indicated by the identified material.

10.5.2 Age of the deposit

The base of the succession was radiocarbon dated to 3300-2700 cal BC, 4330 ± 100 BP (BIRM-328) (Buckland and Dolby, 1973). A sandy horizon *c.* 0.15 m from the base was interpreted as resulting from Neolithic activity on the nearby sand outcrop (Buckland and Dolby, 1973; Dinnin, 1997c). There is no date for the top of the succession, although flooding of the fen is indicated by a clay horizon towards the top of the sequence (0.25 m), which is again overlain by blanket bog. This clay horizon could be alluvium, which was identified at Misterton Carr during recent coring (Dinnin, 1997c). However, it is impossible to tell if this particular clay horizon equates with the alluvial deposits and it would be dangerous to draw any further conclusions concerning the date of the upper part of the sequence without radiocarbon dates. The top of the peat is likely to be prehistoric (P.C. Buckland, *pers. comm.*) and the nature of the faunas are consistent with such a suggestion.

10.5.3 Results

Members of the Carabidae, Hydrophilidae, Staphylinidae, Chrysomelidae, Scolytidae and Curculionidae dominate the faunal assemblage. One non-British species is present, the Eucnemid *Isorhipis melasoides*, a species which has been found elsewhere on the Humberhead Levels from Thorne Moors (Buckland, 1979), as well as in the Somerset Levels (Girling, 1980) and at West Heath Spa, Herts (Girling, 1989).

10.5.4 Environmental reconstruction

The most striking aspect of the Misterton assemblage is the abundance of species associated with trees and woodland. Many of these saproxylics indicate that woodland remains an important element within the landscape for a considerable time.

For instance, the rare RDB 1 scolytid, *Ernoporus caucasicus* is present from the basal sample (37) up to sample 13, 80-75 cm from the top of the succession, sometimes in great abundance (Osborne, 1978). The scolytid is found in the drying branches and twigs of *Tilia* (Palm, 1959), and because populations appear to be restricted to just one or two trees (Hyman, 1992), their frequency highlights the importance and abundance of *Tilia* within the Idle floodplain. Although *Tilia* was present within the Torne floodplain near to Rossington, this tree does not appear to have been represented with such an abundance as at Misterton. *Quercus* was also present, at least during the time represented by the base of the succession, indicated by its leaf-miner, *Rhynchaenus quercus*. Members of the genus *Curculio* are often found on *Quercus*, although some are also found on *Betula* and *Corylus*. *Hedera helix* was also growing, indicated by its beetle, *Ochina ptinoides* (Bullock, 1993).

Fraxinus also appears to have formed an important part of the floodplain woodland community, indicated by its scolytid *Leperisinus varius* (Bullock, 1993). This tree is likely to have remained important within this landscape throughout the succession. *Hylesinus* sp. and *Hylesinus crenatus* are present up to sample 13 (75-80 cm from top of the succession). These scolytids are found under the bark of old *Fraxinus excelsior* trees, although they can also be occasionally recovered from *Quercus* (Palm, 1959). Members of the genus *Scolytus* are also present, which live on a variety of deciduous trees. *Alnus* clearly formed an important part of the floodplain environment throughout most of the period, as implied by its chrysomelid leaf feeder, *Chrysomela aenea*.

There is little indication that *Pinus* was an important component of the landscape. Some members of the genus *Magdalis* live on *Pinus* (sample 15), but several species of the genus also live in deciduous woodland. There are no other species which could confirm the presence of this tree in the vicinity. Members of the genus *Strophosoma* often live in *Calluna* and *Pinus* heaths and the presence of this genus may indicate open areas of heath in the vicinity. The staphylinid *Xantholinus linearis/longiventris* is known to favour heath areas. Exposed areas of the cover sands would have been suitable areas for *Callunetum* to develop, and it is hard not to think that some areas of *Pinus* forest did not develop here.

Not only was the floodplain clearly wooded for a considerable time, but there also appears to have been many old, mature and dead trees in the area. For instance, the rhinoceros beetle *Sinodendron cylindricum* is present up to sample 11 (65-70 cm from the top of the sequence). The larvae and adults of this species are found in old dead wood of a variety of deciduous trees, preferring large diameter trees which are still standing. It can also be found in isolated trees, but is most abundant in old woodland (Garland, 1983). Whilst this species is not considered an obligate old woodland species (for instance, it was recovered in Anglo-Scandinavian deposits from York [Kenward and Hall, 1995]), its abundance is likely to indicate at least old hedgerow trees if not woodland. The non-British rare Eucnemid, *Isorhipis melasoides*, is present up to sample 13 and is typical of *Urwald.* The larvae of this beetle are usually found in standing dead trees, particularly dry red-rotted *Fagus* (Reitter, 1911), but also *Tilia*, *Ulmus* and *Quercus* (Muona, 1993). The NB saproxylic *Melasis buprestoides* is found mostly in dry branches and stumps, where old *Fagus* is preferred (Horion, 1953), although *Betula* and *Alnus* are also known hosts (Garland, 1983). It is characteristic of old woodland, where its development takes at least 2 years (Palm, 1959; Hyman, 1992). The NB Elaterid *Selatosomus bipustulatus* lives individually in dead branches and trunks of various deciduous trees, mostly in fungoid and moss-covered deciduous tree bark and wood, (Palm, 1959) The larvae of *Dalopius marginatus* and *Denticollis linearis* are also found in dead wood of old deciduous trees (Alexander, 1994), although the beetles are often found in woods on flowers (Reitter, 1911).

Leiopus nebulosus is also present in the upper samples. This cerambycid is largely restricted to old woodland (Garland, 1983), where the larvae feed in the cambial layer beneath the bark of dead *Quercus*, although it is also reported in a wide variety of other trees (Alexander, 1994). The continued presence of anobids and cucujids indicates the extensive range of dead wood in the area (e.g. *Grynobius planus*, *Ptilinus pecticornis*; *Pediacus dermestoides*).

There is thus fairly convincing evidence that ancient woodland is indicated by the faunas for a considerable time. This period is represented by the bottom 180 cm of the deposit, at least up until the deposition of sample 13, 75-80 cm from the top of the succession, after which point there appears to have been some sort of environmental change represented. Sample 11 shows diminished woodland, but, by the time sample 2 was deposited (20-25 cm from the top of the succession), there are no woodland-indicating taxa. It is unclear when this transition occurs because the intervening samples were not identified, although it must have occurred sometime after sample 13 was deposited. This sample is roughly contemporaneous with the clay deposit shown in the stratigraphic diagram (Figure 4.12). There is very little in these succeeding samples to indicate what the landscape may have looked like, although the presence of *Phyllopertha horticola*, whose larvae are found on roots of grasses, suggests areas of open landscape. There are no members of the genus *Aphodius* suggesting the presence of herbivores in the vicinity, but the incomplete nature of the identified material indicates that their absence should not be interpreted in a meaningful manner. Earlier samples all indicate a background levels of dung, so there is no reason to believe that this component was absent from the landscape.

The last component of the assemblage which is worthy of comment consists of the aquatic and water-side inhabitants. The presence of the hydrophilid *Hydraena testacea* indicates the presence of stagnant fresh water, where it prefers *Lemna*-covered waters (Lohse, 1971; Hansen, 1987). Other vegetation is indicated by the chrysomelid *Prasocuris phellandrii*, which is found on *Oenanthe* spp. and other aquatic Umbelliferae (Koch, 1992). Vegetation and detritus-rich waters would have been suitable for *Ochthebius* spp. and *Anacaena globosus*. *Limnebius truncatellus*, on the other hand, is found in running water (Friday 1988), although it is also recorded in detritus and flood debris (Koch, 1989). In addition to these aquatics, there are also a small number of riffle beetles, such as *Esolus parallelopipedus* which is found in the mud at the edge of running water (Friday, 1988) and the NB elmid *Oulimnius troglodytes*, which can be found in the wash zone of lakes, as well as in bog pools (Koch, 1989).

It is probable that this aquatic component lived in fen pools on the floodplain, where pools, or meres may have formed on a more-or-less permanent basis. Indeed, the sequence comes from close to the site of what appeared to be a former mere (Buckland and Dolby, 1973). However, it does not appear that such pools were very extensive, or permanent, as the larger Dytiscidae are entirely absent from the samples.

Areas of wet vegetation would have been suitable to a range of different staphylinids, such as *Micropeplus tesserula*, *Acidota cruentata*, *Lesteva punctata* and *Stenus* spp.

One of the basal samples (36) contained a staphylinind, *Microplus tesserula*, which appears to favour burnt forests (Lundberg, 1984; Wikars, 1992; Muona and Rutanen, 1994), although Koch (1989) records amongst its habitats leaves, moss and rotting vegetation. Areas of moist vegetation, possibly beneath woodland would have been suitable habitats for *Loricera pilicornis*, *Bembidion guttula*, *Pterostichus diligens* and *P. nigrita* (Lindroth, 1974).

10.6 Environmental interpretation

The limited fossil insect evidence from Misterton Carr indicates that the floodplain landscape from *c.* 3300-2700 cal BC (4330 ± 100 BP, BIRM-328) (Buckland and Dolby, 1973) was dominated by at least *Tilia*, *Quercus*, *Fraxinus* and *Alnus*. Areas of drier *Pinus-Calluna* heath probably grew on the sand dunes protruding through the peat and abutting the Isle of Axholme.

The floodplain woodland appears to have been primary, undisturbed and seems to have persisted for quite a considerable period of time. *Ernoporus caucasicus* indicates the continued presence of *Tilia* in the landscape up to sample 13 and suggests that the upper part of the sequence probably dates to sometime after the *Tilia* decline. At Rossington, *E. caucasicus* disappears from the fossil insect sequence sometime after *c.* 1690-1450 cal BC (3290 ± 45 BP, SRR-6131), which is roughly analogous with Turner's (1962) primary *Tilia* decline (*c.* 1750-1100 cal BC, 3170 ± 115 BP, Q-481). At Bole Ings, in the Trent valley a few Km south of Misterton, however, this scolytid seems to disappear earlier, after *c.* 2140-1740 cal BC (3570 ± 70 BP, BETA-75271) (Dinnin, 1997e). In the absence of other dates, it seems reasonable to that assume the top of the sequence dates to sometime between *c.* 2000-1100 cal BC. Within this period, the landscape appears to have been cleared of some primary woodland, although it is unclear to what extent, because of the limited nature of the insect evidence. Lithic evidence suggests that there appears to have been rather limited wetland exploitation of the Idle floodplain in this area (Head, 1997, 395). Head (1997) suggests that it is likely that the wetlands were exploited perhaps only at limited times of the year, perhaps seasonally, and that people occupied domestic sites on the areas of higher and drier ground, such as on the Isle of Axholme, which is adjacent to the Idle floodplain. The extensive areas of developing wetlands may have meant that the use of these resources was relatively un-intensive.

An outline, undated, pollen diagram has been recently produced from the floodplain of the river Idle, close to the Roman fortlet and road site at Scaftworth (Van de Noort *et al.*, 1997b), south of Misterton. This core appears to span the period from *c.* 2580-1770 cal BC (4000-3500 BP) to after *c.* cal AD 380-640 (1650-1450 BP). The environment represented is one of *Alnus* carr woodland, with patches of open water and more open farmed areas. *Pinus* was also well-represented in the area. The abundance of ancient woodland indicated by the Misterton faunas is not evident. Apparently reedswamp and fen vegetation initially developed in the vicinity, with floodplain habitats becoming increasingly diverse and extensive. With evidence for over-bank alluviation in the Idle floodplain, the shift in river dynamics probably meant that an ever-changing mosaic and wetland habitats was usual (Dinnin, 1997c).

CHAPTER XI. A PALAEOENTOMOLOGICAL PERSPECTIVE ON HOLOCENE WETLAND DEVELOPMENT IN THE HUMBERHEAD LEVELS.

11.1 Introduction

The palaeoenvironmental record from the Humberhead Levels highlights a series of environmental changes over a period of about 5,000 years. This chapter will discuss the processes behind wetland initiation and development, followed by a discussion of mire ontogeny on the raised bogs and floodplains of the Humberhead Levels, from a fossil insect perspective. Finally, it will also consider the importance of fire within the Humberhead Levels' landscape and its role in the development of mire ecosystems.

11.2 Mire dynamics and formation

Peat growth in raised mires is formed by the accumulation of undecayed *Sphagnum* and of other bog plants, gradually raising the living moss surface above the surrounding area. The characteristic domed profile, with its gently sloping sides, eventually forms. As the bog grows, water is trapped within the dome and water-levels within the bog become independent of the influence of the regional ground water table (Clymo, 1991), although recently this concept has been questioned (Glaser *et al.*, 1997).

Peat accumulation will depend upon the ratio of plant production to decomposition (Damman, 1986) and can vary from little more than 0.5 mm yr^{-1} year (Eggelsmann *et al.*, 1993), to up to 30 mm yr^{-1} in hummock communities and 20 mm yr^{-1} in lawn communities (Ohlson and Dahlberg, 1991). Even within a restricted area on a single mire, there can be a great deal of variation in peat accumulation rates (Ohlson and Dahlberg, 1991). Barber (1993) has suggested that the average accumulation rate of peat is 1 mm yr^{-1} but this remains a matter of debate (see Aaby and Tauber, 1974; Foster and Wright, 1990; Clymo, 1991; Korhola, 1992), and has occasioned some discussion regarding the archaeological context of the bog bodies from Lindow Moss in Cheshire (Barber, 1995; Buckland, 1995). Rates of accumulation also decrease as peat depths increase, but under aerobic conditions, peat accumulation will depend upon decay rates rather than productivity (Damman, 1986). More importantly, the problems of compaction and decay of peat make assessments of peat accumulation rates problematic.

Peat development may be either autogenic (resulting from internal mire processes, such as the silting-up and overgrowth of a lake or depression, known as *terrestrialisation* [Tansley, 1939], Figure 11.3b) or allogenic (resulting from changes beyond the mire margins). Mires may develop due to *paludification* ('swamping') (Figure 11.3a), whereby dry ground becomes wet (*cf.* Walker, 1970). Klinger (1996) points out that mire succession can also occur via *both* terrestrialisation and paludification beginning at the margins of a water body (the "Bog Climax Hypothesis") and views bogs as climax communities (Figure 11.1). External processes such as rising sea level, impeded drainage, climatic cooling and increased precipitation may be causal factors in peat formation (Clymo, 1991; Heathwaite *et al.*,1993).

A minerotrophic mire may develop autogenically into an ombrotrophic raised mire through a variety of processes (Moore, 1993). The build-up of saturated minerotrophic mire peat in a basin or on a flat surface can impede the downward percolation of water, leading to the development of a perched watertable and increased lateral flow of water. This process may be facilitated by the amorphous structure of humified minerotrophic fen peat. Increased isolation from nutrient-charged groundwater sources leads to increasingly nutrient-deficient hydrological conditions that favour poor fen communities and *Sphagnum* growth. As peat continues to accumulate, the mire surface grows above the general level of the surrounding land and associated regional watertable, sustained by its own independent perched watertable. This process may be further enhanced by the ability of the saturated *Sphagnum* remains to retain water and the presence of methane gas bubbles in the catotelm[1] peat (Brown D.A., 1997). Once this stage has been reached, the hydraulic gradient will tend to transport water laterally towards the margins of the mire, preventing the influx of nutrient-charged water from adjacent land. As the peat body becomes essentially ombrotrophic (i.e. sustained by precipitation falling directly onto the mire surface), the low ionic content and acidity of rainwater water input means that the system becomes oligotrophic.

Alternatively, a minerotrophic mire may develop allogenically into ombrotrophic raised mire as a result of surface paludification which initiates minerotrophic mire development. As in the above sequence of events, peat formation and impeded vertical percolation of water eventually leads to the development of a perched watertable, culminating in ombrotrophic mire formation. In this scenario, the peat succession may follow a similar path to that above, from minerotrophic fen peat, mesotrophic peat to ombrotrophic mire peat, providing an example of equifinality (*cf.* Buckland and Smith, *in press*), where different mire initiation processes lead to the same result: raised mire.

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[1] Catotelm is the permanently saturated peat beneath the acrotelm, mainly anoxic and with a low hydraulic conductivity. The acrotelm is the surface layer of a raised mire that is not permanently saturated, comprising the living plant cover and recently deposited peat.

11.3 Factors contributing to wetland initiation and development in the Humberhead Levels

The commencement of peat development itself is an indication of hydrological changes. A number of factors may have affected the development of wetland in the Humberhead Levels and these are considered in turn:

- Climate change
- Sea-level rise
- Anthropogenic activities
- Natural fires
- Other factors

In addition, a series of models have been proposed concerning wetland development (cf. Buckland, 1979; Buckland and Sadler, 1985; Buckland and Smith, *in press*) and these are considered in turn, together with the palaeoecological evidence from the mires and floodplains.

11.3.1 Climate change

An extensive literature deals with the role of climate in peat inception and development (e.g. Sernander, 1908; Aaby and Tauber, 1975; Godwin, 1981; Barber, 1981, 1985; Foster and Wright, 1990; Glaser *et al.,* 1997). Mire development has been regarded as a consequence of a shift to wetter and/or cooler climates (Moore, 1986). Shifts from drier to wetter conditions have been noted at a number of peatland sites in Britain, *c.* 4000 cal BC, (Barber *et al.*, 1994) and wetter climatic conditions appear to have existed between *c.* 3300 and 3000 cal BC (Barber *et al.*, 1994). In southern Finland, Korhola (1992, 1995) noted an important phase of peat initiation from 4300 to 3000 cal BC. Individual bogs may show, however, a time-lag in their reaction to climate change (Kilian *et al.*, 1995). The dating of these phases is also dependant upon the radiocarbon dating of bulk peat which may be subject to errors of up to 500 years due to the "reservoir effect"[2] (Kilian *et al.,* 1995).

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[2] The "reservoir effect" means that the carbon source of raised bog plants is different to atmospheric CO^2, yielding older dates. This is probably caused by bacteria in the catotelm fixing old CO^2 in the root zone.

The idea that climate change may be the driving factor behind peat initiation has led researchers to suggest that peat deposits are important proxy records for climatic change. This originates from the fundamental significance of water in controlling mire surface plant communities and consequently peat composition. The growth of ombrotrophic bogs is thought to be related to atmospheric inputs, with a direct relationship between the growth of the water dome within the mire and precipitation levels (i.e. the balance of precipitation minus evaporation, surface runoff, lateral catotelm discharge and groundwater recharge/vertical percolation) (Bragg 1988; Ingram 1982; Damman, 1986; Glaser *et al.*, 1987). This is coupled with the rate of decomposition of accumulating peat (Clymo, 1991). Consequently, changes in the mire surface wetness, indicated by variations in plant composition and degree of humification of the stratified peat archive, reflect the precipitation-evapotranspiration balance, which in turn is seen as being a function of climate (Barber 1981; 1982; 1985; Blackford, 1993; Barber *et al.*, 1994). Barber (1981, 1985) suggests that rapid accumulation of unhumified *Sphagnum* peat over a site must be indicative of a cool, wet climate with a high precipitation/evaporation balance (Barber, 1981).

Some of this research is based upon the occurrence of recurrence surfaces (seen as abrupt changes in the degrees of humification between peats), which have been used to indicate a major change in the conditions of peat formation. Weber (1911) proposed the idea of the *Grenzhorizont*, a term originally introduced to describe the *Calluna* and *Eriophorum* layers of the boundary peat, to mark the abrupt change in *Sphagnum* decomposition in north-western and central European mires. Weber (1911) attempted to link peatlands in different geographical locations to the same fluctuations of climate on the basis of the *Grenzhorizont*. However, the available peat stratigraphic evidence suggests that recurrence surfaces are not as regular or as simultaneous as originally proposed (Gore, 1983). Recent research has attempted to use different degrees of humification levels to examine wet/dry fluctuations (e.g. Chambers *et al.,* 1997). However, these changes in stratigraphy, as well as changes in different bryophytes living on mires (*cf.* Barber, 1981; Barber *et al.*, 1994), may have occurred in response to local edaphic changes, such as in the local drainage pattern in the vicinity of the mire and aspects of autogenic vegetational and hydrological processes (Smith, 1985; Foster and Jacobson, 1990; Foster and Wright, 1990). Peat humification is controlled not only by the mire surface conditions at the time of peat formation, but also by *subsequent changes in water levels*. Thus, a relatively humified peat layer may form either as a result of dry mire surface conditions at the time the plant material was initially deposited, or from the humification of formerly waterlogged and virtually unhumified peat following a phase of lower water-table (Eggelsmann *et al.*, 1993). Other research highlights the importance of lateral expansion of mires (Foster and Wright, 1990; Korhola, 1995) which suggests that the volumetric lateral growth of mires can be large, even though there might be only minor vertical growth (Tolonen and Turunen, 1996). This signifies that phases of expansion of the mire area may be as important indicators of mire change, as vertical accumulation and changes indicated therein. In addition, much of the research regarding the climatic signal in peats is based upon the study of ombrotrophic peats; the growth of rheotrophic and mesotrophic peats, such as those at the base of Thorne and Hatfield Moors, may have been subject to a range of other factors (*cf.* Almquist-Jacobson and Foster, 1995)

Research indicates that the response of mires to climate is far from straightforward and the understanding of how these systems work is incomplete (Foster and Wright, 1990; Glaser *et al.*, 1997). It may thus be almost impossible to isolate climatic influences on mire formation from the autogenic changes in mire hydrology, chemistry and biota as the mire develops (Heathwaite *et al.*, 1993). Studies of carbon isotope variations in *Sphagnum* may be one way of isolating climatic trends from autogenic factors (*cf.* Price *et al.*, 1997).

Most mire research has been conducted in areas where there is high precipitation, where bogs are frequent (Moore, 1997). However, mires also form in areas where precipitation is low. Thorne and Hatfield Moors are located in a climatically marginal area for the development of raised mire (Money, 1995). Research carried out on the bogs of north-west Minnesota, which have formed in an area of relatively low precipitation, suggests that bogs are able to draw-up water from the underlying mineral subsoil into the dome during periods of low rainfall (Glaser *et al.*, 1997). This has the effect of maintaining the bog water-table independently of precipitation falling on the bog. During wet periods there is a reverse movement as a consequence of the excess of supply of water from rain, generating sufficient hydraulic head to drive surface water downwards. It thus appears that, in certain circumstances, groundwater may be an essential ingredient for the formation and maintenance of such raised bogs (Glaser *et al.*, 1997). The raised mires of the Humberhead Levels may have periodically made use of such a ground-water draw-up mechanism. Glaser and colleague's (1997) conclusions thus raise some very serious and pointed questions with regard to the degree to which mires are climatically controlled, and conflict with the basic premise that they are ombrotrophic and completely disconnected from groundwater (*cf.* Ivanov, 1981; Ingram, 1982).

Indeed, for some periods, bogs may become decoupled from direct climatic control (Glaser *et al.*, 1997).

All this evidence suggests that using mires to examine climate change is problematic. The use of alternative proxies to examine possible links between climate change and the onset of peat initiation in the Humberhead Levels is preferable. If the climatic record from mires is discounted, what evidence is there for a change in climate around the time of peat initiation in the Humberhead Levels?

Boswijk's work (1998) indicates that the demise of the oaks from Thorne Moors was occurring at the same time as trees from Melton, East Yorkshire, suggesting similar regional links in the demise of these trees. This may, of course, have little to do with climate change, rather than reflecting hydrological changes within the Levels. However, she notes that a number of different wetland sites with dendrochronologically dated trees show declines between 2700 and 2400 BC, indicating that an environmental threshold was crossed at this time on many wetland sites. Boswijk (1998) suggests that that there is thus some evidence to suggest changes in precipitation levels at around the time of the decline of woodland on the mires of Thorne and Hatfield Moors.

The insect evidence from the mires and floodplain deposits do not highlight any evidence for climate change which could explain the onset of peat formation, although some of the faunas may suggest a more continental climate (Roper, 1993; Whitehouse *et al., 1997*; Chapter 12). However, it is unclear when such a transition may have occurred. Osborne (1976; 1982; 1988) suggests that there is evidence for a climatic deterioration, or at least a cold period about 5,000 years ago, followed by an increase in temperatures between 4,000-3,000 years ago. Girling (1984) argued on the basis of the presence of thermophilous Carabidae that temperatures may have been higher during the late Neolithic/Bronze age. Dinnin (1997e), discussing faunas from Bole Ings, Nottinghamshire, argues that a shift towards a more oceanic climatic regime may have played a decisive role in the extinction of some of the more continental taxa recovered from Holocene deposits. However, there are still too many gaps in the fossil insect record and too limited knowledge concerning the factors controlling distributions to draw any firm conclusions from the insect evidence (see Chapter 12).

Research carried out on fossil *Pinus* trees from Fennoscandia suggest that warmer conditions were prevalent in northern Europe until *c.* 6000 years ago, although there were some regional differences, but that a climate shift was experienced *c.* 3800 BC (Eronen and Zetterberg, 1996). Studies of fossil *Pinus*-wood in Scottish peats suggests a decline of this tree about 4000-3500 years ago (Bridge *et al.*, 1990, Gear, 1989; Gear and Huntley, 1991). Climate change has been invoked for this decline, where a continental regime was replaced by a maritime type climate, resulting in decreased seasonality and increased precipitation (Gear, 1989). Anderson (1998, 218) however, notes that the climate link to this deforestation may not be straightforward because the decline appears to have occurred over a protracted period of time. In addition, the decline of many of these trees may be connected with the onset of peat formation on many sites so the argument becomes rather circular.

However, on the basis of isotope studies on fossil pinewood from the Cairngorms Dubois and Ferguson (1985) argued for an increased period of precipitation between *c. 4800 and* 4400 cal BP (*c.* 2900-2500 cal BC or 4200-4050 BP). More recently, Bond *et al.* (1997) highlight evidence for several ice-rafted debris events during the Holocene associated with brief periods of lower sea surface temperatures from deep sea cores. The sediments highlight a series of episodes when cool, ice-bearing waters moved southwards from Greenland-Iceland waters. One of these events is dated to *c.* 4000 cal BC (*c.* 5900 cal BP), followed by an event dated to *c. 2250 cal BC (c. 4200* cal BP). These events would have brought about changes in the circulation and sea surface temperatures of the North Atlantic Ocean, possibly bringing about increased precipitation and cooler temperatures.

11.3.2 Sea level rise

Gaunt and Tooley (1974) presented evidence for several episodes of sea-level change in the Humber estuary during the mid-Holocene period. Sea-levels rise would have created transgressions in certain areas of the Humber lowlands and Lincolnshire and played a significant role in raising the regional water table. Gaunt and Tooley's (1974) work has been expanded and augmented by recent research by Dinnin and Lillie (1995) and Long *et al.*, (1998). Dinnin and Lillie produced a comprehensive review of the sea-level data, including new stratigraphic investigations of southern Holderness. Their chronology of coastal evolution differs from Gaunt and Tooley's and appears to highlight several problems in the original scheme.

Long *et al.* (1998) have produced a comprehensive re-evaluation of the data, together with new evidence. They suggest that the first reliable date for sea level rise/coastal evolution is from Gaunt and Tooley's (1974) site at Market Place (Hull), which records inundation of low-lying coastal woodland at around 5986-5607 cal BC (6970 ± 100 IGS C14/99); Long *et al.'s* (1998) dates from Union Dock (Grimsby) indicate a positive sea level tendency at about the same time, 4940-4710 cal BC (5900 ± 45 BP, SRR-4745).

Gaunt and Tooley (1974) also recorded evidence for a marine transgression from estuarine clays overlying peaty deposits dated to about 2866-2142 cal BC (3943 ± 100 BP, Q-685) at Chapel Point on the Lincolnshire coast. There followed a general trend in sea level rise up to about 3,000 years ago (*c.* 1050 cal BC) (Long *et al.*, 1998).

Between *c.* 1550-950 cal BC (*c.* 3500 and 2900 cal BP, Subboreal/Subatlantic transition), there is evidence for more widespread expansion of marine conditions in the Humber estuary (Long *et al.*, 1998). The maximum extent of marine incursion appears to be represented at Newton Marsh, in the outer Humber Estuary, dated to *c.* 1220-840 cal BC (2840 ± 60 BP, RCD-1598) (Long *et al.*, 1998). This incursion is also represented in the Ancholme Levels at Brigg (Smith, 1958b), sometime before *c.* 1259-799 cal BC (2784 ± 100 BP, Q-78) (Buckland, 1981). A decline in esturine influence had occurred by the time the "raft" at Brigg was buried, by *c.* 903-603 cal BC (2625 ± 65 BP, CAR-60) (Buckland, 1981). Evidence from elsewhere indicates the disappearance of estuarine conditions, such as the sediment entombing of the logboat at Hasholme (Holderness), which dates to sometime after 322-277 BC, based on the dendrochronology of the boat timbers (Millett and McGrail, 1987). By the Roman period, seaward portions of the lower Hull valley were no longer permanently under water (Long *et al.*, 1998). In consequence, the regional water table during the Roman period may have been rather lower. During this drier period larger areas of land appear to have been occupied and cultivated (Buckland and Magilton, 1986; Chapman, 1997) and may explain the high density of Roman occupation. However, a positive sea-level tendency has been noted towards the end of the Roman period and afterwards (Dinnin and Lillie, 1995).

During these periods of marine transgression, marine conditions penetrated deep into the Humber estuary and its tributary valleys (Long *et al.*, 1998). However, there is no palaeoecological or stratigraphic evidence which suggests the penetration of marine or estuarine conditions in the Levels, despite the fact that the base of the peat deposits at Thorne Waste now lie over 4 m below high water at Goole (Buckland, 1979). Both the palaeoentomological (Buckland, 1979; Buckland and Sadler, 1985; Roper, 1993; Whitehouse, 1993; 1997; this research) and pollen analytical evidence (Turner, 1962; Smith, 1985) from the mires and floodplains across the Levels do not indicate the presence of any saline influences.

The marine incursion noted by Gaunt and Tooley (1974) at Chapel Point occurs around the same time as peat initiation on the raised mires of the Humberhead Peatlands. However, it is unlikely that peat deposition began in response to this transgression, since peat initiation had already commenced on the two sites. Elsewhere in the Levels (e.g. on Torne floodplain), wetland development had also commenced. It is likely that the general trend in sea level rise at this time caused a backing-up of freshwater runoff from rivers, which run into the estuary, causing freshwater flooding rather than an influx of saline conditions (Buckland, 1979). This would also have affected levels of water within the underlying water-table.

11.3.3 Anthropogenic activities

Several researchers have suggested that peat initiation may be related to human activities (*cf.* Moore, 1973, 1975, 1993). It is postulated that land clearance may have led to increases of water run-off from higher ground into river systems, causing changes in the hydrological balance, leading to peat initiation (Moore, 1975; Moore and Wilmott, 1976). The clearance of closed forest can produce a considerable increase of the water-table. For instance, clear cutting of forest in Finland has caused a rise in the water table by 38 cm (Moore, 1975). Even small-scale clearances would have generated an increase in water table levels (Buckland, 1979). However, there is very little evidence from the Humberhead Levels of even small scale clearance at the time of peat initiation (Smith, 1985). The fossil insect evidence very clearly indicates the presence of relatively undisturbed woodland on and in the vicinity of the raised mires. Evidence from both Misterton Carr and Rossington also corroborate this. In the Torne floodplain, widespread woodland clearance did not occur until at least the later Bronze age. In the vicinity of the Idle, at Misterton Carr, floodplain woodland appears to persist until late into the prehistoric period, possibly into the Iron age.

Mather (1991) identified possible evidence of Mesolithic forest exploitation using fire in the vicinity of the Torne floodplain. However, he did not consider the possibility of natural fire occurring (*cf.* Whitehouse, 1997a, Dinnin, 1997b), particularly given the abundance of *Pinus*-dominated woodland which is known for its flammable qualities (Wagner, 1983). In addition, on at least one occasion, fire may have burnt on the fen carr itself. The abundance of reed material and plant litter indicated by the fossil insect record indicates that such material may have been particularly flammable, particularly during periods of seasonal dryness.

The burnt trees at the base of the mires at Thorne and Hatfield Moors have been interpreted as representing a Neolithic or Bronze age clearance event (cf. Buckland and Kenward, 1973 Buckland, 1979). If, as Roper (1996: 519) suggests, the burning represented a number of smaller fire events, then the piecemeal reduction in tree cover may have resulted in a rise in the local water table. However, the dendrochronological work (Boswijk, 1998) indicates that the trees living on the mire were contemporaneous with the early stages of mire development on the two sites. In addition, the fossil insect evidence from the woody peats suggests that mesotrophic and ombrotrophic conditions had already developed, prior to the woodland burning (Roper, 1993; Whitehouse, 1993, 1997a, Chapters 7 & 8, Boswijk, 1998), although burning of the mire woodland may have accelerated processes which had already begun. Thus, burning of the woodland cannot be viewed as a contributory factor to wetland initiation, although it may have contributed to its continued development.

There is very little evidence for clearance within the Humberhead Levels around the period of peat initiation, which could be responsible for increasing water run-off into the region's rivers. However, there is palynological evidence upriver which indicates clearance beyond the region, such as the Pennines, where peat development had already begun by *c.* 7000 uncal BP (e.g. Jacobi *et al.,* 1976; Williams, 1985; Simmons and Innes, 1987).

11.3.4 Natural fires

Recent research suggests that fire may have an important role to play in the development of peatlands (Moore, 1996). The frequency with which charcoal and charred trees are encountered at the base of mires (e.g. Tallis and Switsur, 1983; Gear, 1989; Korhola, 1992) suggests that fire may be a natural feature of the *Pinus*-mire ecosystem (see section 11.8). The presence of charcoal in sediments can influence water movement patterns to such an extent that drainage is impeded and the local water table is raised, with the subsequent development of wetland communities. The redistribution of charcoal in soil profiles may even provide the waterlogged conditions necessary for peat initiation and formation (Mallik *et al.*, 1984; Moore, 1996). On both Thorne and Hatfield Moors (and elsewhere in the Humberhead Levels), charcoal deposits are extensive. As stated previously, the evidence indicates that the mire/woodland was burnt *after* peat initiation.

However, the occurrence of burnt *Quercus* and *Pinus*-wood and the frequent occurrence of charcoal through many of the profiles raises some very interesting questions regarding the importance of fires within the development and maintenance of mire forests and mire ecosystems.

11.3.5 Other factors

A number of other factors have been highlighted as being contributory to wetland development, such as the activity of animals like beavers (Coles, 1997). The hydrogeomorphological effects of beavers have been recently reviewed by Gurnell (1998). Beavers can greatly affect their environment by constructing dams, canals and other structures which can affect ecosystem structure and dynamics well beyond the immediate environment (Gurnell, 1998) The presence of beaver during prehistory has been noted at a number of different sites (Coles, 1997). There is a strong possibility that beaver activity may have periodically affected floodplains areas of the Levels.

11.3.6 Models

Buckland (1979) and Buckland and Sadler (1985) provided flow diagrams summarising the probable factors influencing the development of wetlands in the Humberhead Levels (Figure 11.2). This model stressed the influence of raising base levels associated with an increase in run-off due to forest clearance activities in the catchment of the rivers in the area; clearance of forest on the Levels would have further exacerbated the problems of a raising water table, leading to paludification.

More recently, the origins of the Moors have been the focus of several papers (Buckland and Smith, *in press*; Roper, 1993, 1996; Dinnin, 1994). Buckland and Smith (*in press*) in particular, focus on a series of models of bog development, each resulting in raised mire: equifinality (Figure 11.3). They see a progressive rise in the water table, rather than a wetter climate as the prime mover in bog genesis. They suggest, in particular, that the absence of an underlying Holocene lake basin (see Roper, 1993; Buckland and Smith, *in press*) indicates a rising base level, leading to paludification of several centres in the form of small pools. Alternatively, peat growth may have initiated from the river floodplains, or a riverine mere, but as Buckland and Smith (*in press*) point out, if mire development had spread laterally from the Ouse and Trent or the Idle and Torne, the relevant areas would now be buried beneath recent warp and alluvium or destroyed by peat cutting. In summary, they ask whether peat growth resulted from lateral expansion from the margins of the river courses, or whether it was *in situ* growth leading to the development of the raised mire complexes (Buckland and Smith, *in press*, 4).

11.4 Ontogeny of Thorne and Hatfield Moors.

Radiocarbon dates (Smith, 1985, Chapters 6 and 8) (Figures 8.8 and 7.5) indicate that peat initiation in some areas of Thorne and Hatfield Moors began more-or-less simultaneously, at least by *c.* 3350-3100 cal BC (*c.* 4500 BP), suggesting similar causal factors. The earliest date for peat inception on Thorne Moors is from Rawcliffe Moors, on the north side, dated to 3370-3100 cal BC (4545 ± 75 BP, CAR-221). However, Boswijk's (1998) *Quercus* chronology of 3777-3017 BC suggests that peat formation had already begun in areas of Rawcliffe and Goole Moors by the mid 3000's BC (Boswijk, 1998). On Hatfield Moors, the earliest date is from the north side of the present site, on Kilham West (HAT 3), dated to 3350-2930 cal BC (4480 ± 45 BP, SRR-6119). Whilst Thorne Moors contains extensive evidence for rheotrophic mire development (Smith, 1985), this is not the case for Hatfield Moors. This suggests differences in the development of the two mires.

No evidence has been found for a reedswamp phase on either Moors, representing the infilling of a lake basin (*cf.* Roper, 1993, Chapters 7 and 8) and it is likely that paludification of a former dry land surface occurred. The importance of rising base levels appears to be indicated from the palaeoentomological data from both Moors. *Aquatic Coleoptera* species which require relatively extensive areas of open water are present within basal samples from both mires (*cf.* Roper, 1993; Chapters 6 and 8) and chart the transition from eutrophic fen to acid raised mire.

Sea-level rise was probably a strong contributory factor to wetland initiation. There is no evidence for marine incursion and a rise in sea-levels would have increased the regional water-table in an area of low altitude. Waterlogging would inevitably have ensued. Despite the problems associated with the use of peat as a proxy for climate change, peat inception appears to have occurred during a period of major environmental change, possibly during a transition from a continental to more oceanic régime. There is some insect evidence which could tentatively support a transition from continental to more oceanic climates sometime during the mid-Holocene, although it is difficult to know when such a transition occurred (Whitehouse *et al.*, 1997, and Chapter 12). Many of the non-British species which could signify a more continental climate continued to live on Thorne Moors until paludification of the forest on the south side of Thorne Moors *c.* 1680-1440 cal BC (3260 ± 100 BP, BIRM-335). The frequency of fires in many mires of this date may also lend some very tentative support to such an interpretation (see section 11.8). The age range of radiocarbon dates makes correlation between peat initiation and climate change problematic, although the evidence could support a gradual transition of climate during this period, contributing to peat development in the area. As Buckland (1979) points out, however, it is likely that other factors played a more important role in peat initiation and development.

The fossil insect and other palaeoecological data suggests that there is little or no anthropogenic activity which could have destabilised the landscape at this time, although activities further up-river could have contributed to rising water levels. Mire fires may have exacerbated a process of wetland development which had already begun.

It would thus seem that a combination of different factors contributed to mire genesis and development. It is worth noting that different mire-initiation processes may have promoted mire initiation in different parts of the mires (*cf.* Korhola, 1995, 44) although once initiated, it is likely that periods of expansion or rapid/slow peat accumulation were linked to autogenic processes.

11.4.1 Thorne Moors

Thorne Moors developed in a markedly different way to Hatfield Moors, having three stages of development. Initially, rheotrophic mire formed, followed by an intermediate (mesotrophic) mire stage, into ombrotrophic raised mire. The first two stages were influenced by the hydrological conditions in the vicinity of the developing mire. Once those factors ceased to be important, ombrotrophic mire developed.

Prior to and during the early stages of paludification and peat growth, relatively undisturbed mixed deciduous forest covered Thorne Moors (Smith, 1985; Roper, 1993; Whitehouse, 1993, 1997a; Dinnin, 1994; Boswijk, 1998). This forest was initially *Quercus*-dominated forest, forming a relic of the widespread woodland growing in the Levels between at least 3777-3017 BC, and this was later superceded by *Pinus*-dominated forest. This early phase of woodland is illustrated by the faunas from Blackwater Dike, Goole Moors, on the northern side of Thorne Moors, which indicates that rheotrophic mire development had already been initiated during this early phase. The demise of this early woodland occurred sometime around 3000 BC (Boswijk, 1998). The insect data indicate the onset of wetter conditions and that acidity and water levels are positively correlated with this transition from deciduous- to coniferous-dominated woodland, although a temporary period of mire dryness may have enabled *Pinus* to dominate the woodland growing on the mire surface. An episode of fire may have also contributed to the transition to *Pinus*-woodland. The upper fossil insect samples from Blackwater Dike and those associated with a *Pinus* on Snaith and Cowick Moors (Whitehouse, 1993) indicate a mixture of rheotrophic and ombrotrophic species, suggesting that the *Pinus* phase is a mesotrophic one. Succession developed from this mesotrophic poor fen to ombrotrophic and oligotrophic bog (Smith, 1985). Roper (1993, 1996) studied beetles which spanned this transition from eutrophic fen to ombrotrophic raised mire and showed how this transition exacted a profound change on the faunas.

On the south side of Thorne Moors, peat initiation was delayed by about 1000-1300 years. The base of the peat at the trackway site indicates peat initiation *c.* 1680-1440 cal BC (3260±100 BP, BIRM-335). The construction of the trackway itself was probably in response to increasingly wetter mire conditions. The basal topography in this area is higher than in other areas, and this could have slowed the spread of fen to the south-east. The mire faunas from this location indicate that *Urwald* woodland had managed to persist in this marginal area of the mire (Buckland, 1979), until it was superseded by mire.

The range of aquatic beetles recovered from all these phases indicate that bog pools were important mire components from its inception onwards. Historical evidence suggests that pools and surface patterns were important elements on Thorne Moors up to the closing decades of the 19th century (Casson, 1869; Woodruffe-Peacock, 1920-21). The first edition 1853 O.S. map of Thorne Moor illustrates an abundance of mire pools, many randomly distributed across the mire, but some follow a roughly concentric pattern around the central areas of the Moors (Figure 11.4). Buckland and Smith (*in press*) note that this topographic evidence would suggest at least four "topographic centres" to the mire and that there may have been others. Palaeoecological evidence indicates that such pool systems are important, long-persistent features of mires (Casparie, 1972; Aaby, 1976; Hulme, 1976; Tallis, 1983; Tallis and Livett, 1994). Their occasional expansion and contraction indicated by expansion and contraction of aquatic insects suggests that they are sensitive to climatic and /or hydrological changes.

Figure 8.8 illustrates how peat initiation dates are distributed in a non-linear, time-transgressive fashion. The correspondence analysis presented within Chapter 9 highlights the fact that Thorne Moors fossil insect assemblages are heterogeneous, particularly at site level. They support the idea that peat initiation may have occurred polyfocally (*cf.* Buckland and Smith, *in press*), perhaps in some cases in relative isolation, thus creating the temporal and landscape heterogeneity evident amongst the Thorne Moors' entomofaunas. However, Boswijk (1998) argues that the dendrochronological evidence supports the idea that mire developed through terrestrialisation from a single *focus*. The entomofaunal results could be best explained if a mosaic of different habitats existed across Thorne Moors, brought about by the time-transgressive nature of peat development.

Boswijk's (1998) research provides some indication of the temporal span represented by each of the different phases at Thorne Moors. Whilst rheotrophic conditions spread comparatively rapidly over the area, over a maximum of *c.* 500 years, mesotrophic poor fen seems to have persisted for over a 1000 years. The spread of mesotrophic mire was not a continual process, but occurred in a series of expansion phases, separated by periods of mire dryness, when *Pinus* was able to colonise the mire surface. Plate 11.1a, b shows *Pinus* which has colonised the surface of a mire in Sweden (P. Buckland, *pers.*

comm.). The transition from *Quercus* woodland to ombrotrophic mire took a total of *c.* 2500 years across Rawcliffe, Goole and Crowle Moors (Boswijk, 1998). On the south side of Thorne Moors, there was a more rapid progression from the formation of the basal peats to ombrotrophic conditions, taking *c.* 1000 years (Boswijk, 1998).

11.4.2 Hatfield Moors

Most of the entomofaunal evidence suggests that mesotrophic mire developed over the original land surface on Hatfield Moors and that ombrotrophic peats developed rapidly above these basal deposits. It is difficult to say how rapidly this transition occurred, although in some cases it appears to have occurred in less than a few hundred years (e.g. at Kilham West; Tyrham Hall Quarry). The environmental data represented by the single Tyrham *Quercus* and its rot hole (3618-3418 BC) probably represent pre-peat landscape conditions, suggesting *Quercus-Betula*-dominated fen woodland. The range of radiocarbon dates across the site suggest that mire development occurred more or less simultaneously, centering around 3000 cal BC (see Figure 7.5). These dates correlate closely with rheotrophic fen peat development on Rawcliffe Moors (Thorne Moors) (Smith, 1985), suggesting similar causal links in the Moors' development.

This initial phase of peat development overlapped with the growth of the *Pinus* woodland (2921-2445 BC), at least at Tyrham Hall Quarry and Kilham West. The insect evidence suggests that during the initial stages of peat growth, mesotrophic *Calluna-Eriophorum* heath and *Pinus-Betula* forest covered much of the land surface, but that increasingly ombrotrophic and wet conditions developed. The excellent condition of some of the tree macrofossils on Hatfield Moors indicates the rapidity with which the developing mire engulfed the woodland. The chronology of the trees, together with the fossil insect evidence would suggest that mesotrophic conditions gave way to ombrotrophic ones in about 500 years (the length of the chronology), since trees were no longer able to live after 2445 BC and the insect evidence includes species typical of acid raised mire.

The presence of the dry *Calluna* acid-heath which formed part of the pre-peat landscape may explain this rapid transition from mesotrophic to ombrotrophic conditions. The presence of *Pinus* across the site may have accelerated the process of paludification, as coniferous forest lowers soil pH, making conditions more condusive to the establishment of *Sphagnum* and further acidity (Hulme, 1994). An increase in water levels across the site would have enabled a transition from drier to wetter conditions, thus facilitating this change in trophic status. The development of a podzol and iron pan in the wind-blown sands may have contributed to waterlogging, by creating a barrier through which surface water would have had difficulty draining away.

Most of the basal deposits are characterised by amorphous black, very well humified peat, containing abundant mineral material, sometimes with *Eriophorum vaginatum* remains. Oscillation of the mire water-table and occasional drying out may have led to the formation of these extensively humified deposits, a feature often seen in blanket mire (Buckland and Smith, *in press*). Ombrotrophic peat rarely develops directly above basal mineral deposits, which are usually characterised by organic lake muds and fen peats (Smith, 1985). Once formed, the amorphous peat would have created an almost impenetrable barrier between the mire and the underlying water table. It is notable that even a small increase in the supply of water or decrease in evaporation could result in a considerable rise in water level due to this barrier effect (*cf.* Svensson, 1988).

Much of the radiocarbon dating and fossil insect evidence suggests that peat development occurred more-or-less simultaneously across the site, either from a particular point or perhaps in different areas (poly-focally), which then coalesced. It has already been pointed out that few basal peat dates are available for the eastern side of Hatfield Moors. The proximity of the Rivers Torne and Idle which enclose the site on its south and south-eastern margins may also have affected development. One of the encircling rivers, the Torne, had begun to accumulate peat at least by *c.* 4340-4040 cal BC (5340 ± 45 BP, SRR-6136), possibly earlier. The eastern part of Hatfield contains several topographic low points, where the peat-mineral interface drops to -0.9 m OD in places. The point of origin of Hatfield Moors may lie somewhere within these lower areas (generally on the eastern side) or off the present margins of the Moors, somewhere in the vicinity of the river floodplain. A series of dates from the eastern edge of Hatfield Moors would perhaps solve this question. However, the valley-mire initiation model (Buckland and Smith, 1985) predicted that the age of basal peat deposits would be progressively younger away from the river, which is clearly not the case. Indeed, the earliest dates come from the vicinity of Tyrham Hall Quarry and Kilham West, on the western and northern sides of Hatfield. This evidence would supports *in situ* growth, probably more-or-less simultaneously, from a number of different centres. Development may have occurred within the low points between the sand dunes (see Figure 11.3c). The exposed dunes would have effectively conducted water downwards, as well as acting as areas of preferential surface water run-off. If the underlying water-table lay close to the base of the dune low points or hollows, areas of standing water could have developed, creating anaerobic conditions which would enabled the build-up of plant enabled the build-up of plant matter, and have rapidly been followed by the onset of peat accumulation. Peat development within the hollows would have continued to develop upwards, before rising above the sands and moving outwards. This could have occurred through the process of both paludification and terrestrialisation (*cf.* Klinger, 1996, see Figure 11.1), with the establishment of peat-forming communities in the hollows, on the margins of small pools or ponds within these lower areas. Peat accumulation would have been via both terrestrialisation and paludification with the continued rise in the water levels and continued paludification outwards of the hollows would have resulted in the formation of ombrotrophic mire. It is possible that peat developed in such a manner in several different places, before forming a coalesced whole or initiated from just one particular location, rapidly burying the previous land surface. Unfortunately, it is not possible to test this hypothesis as there has been no investigation of peat deposits within the "hollows".

Rheotrophic fen peat was encountered on the south side of the Moors (Packards south, HAT 4 site), where the remains of *Phragmites* were noted in the basal deposits. The insect assemblages from HAT 4 indicate the presence of a lagg fen community on the southern margins of the developing mire. Peat development in this area was delayed by *c.* 1500 years compared with Tyrham Hall Quarry, and is in the vicinity to an area of slightly higher ground. This area may have become incorporated by the mire following a phase of mire expansion at *c.* 1520-1390 cal BC (3164 ±40 BP, SRR-6127). Ombrotrophic conditions developed in this area about 500 years later.

There appear to have been several identifiable episodes of "forest" growth, perhaps during phases of drier mire surface when *Pinus* would have been able to temporarily expand across the mire surface (Smith, 1985). Boswijk (1998) identified growth flushes which enabled *Pinus* to expand across Thorne Moors, and it is possible that *Pinus* behaved in a similar manner on Hatfield. Similar distinct phases of mire *Pinus* woodland have been identified elsewhere (e.g. White Moss, Cheshire, Lageard *et al.*, 1995). In contrast to Thorne Moors, however, the insect evidence indicates the longevity of *Pinus sylvestris* on Hatfield Moors and supports the widely held view that the population of *Pinus sylvestris* living on the margins of the Moor and Lindholme Island today are the descendants of the Bronze age forest buried in the basal peats (Skidmore *in press*).

11.5 Floodplain development in the Humberhead Levels

Whilst peat development was beginning on Thorne and Hatfield Moors, extensive areas of wetland development had already commenced on the Humberhead Levels' floodplains.

During the early Post-glacial, the rivers of the Humberhead Levels underwent a phase of rapid incision in response to lower sea levels. This phase ended long before 5740-5410 cal BC (6681 ± 100 BP, Q-401), when sea levels in the Humber estuary had risen to about -9 OD (Gaunt and Tooley, 1974). There is evidence to suggest this process had already ceased by 7500 cal BP (*c.* 5550 cal BC or 8500 BP) (Gaunt, 1987).

As sea levels continued to rise, channel aggradation occurred. The subsequent conditions enabled the development of peat in the floodplain areas. Investigations at Thorne Waterside, west of Thorne town, of sediments originating in the channel of the old river Don, indicate floodplain peat initiation at *c.* 3020-2620 cal BC (4230 ± 100 B.P, BIRM-358) (Buckland, 1979). A similar date was obtained from the Crowle Depression, Thorne Moors, representing the base of the Don *c.* 2920-2660 cal BC (4230 ± 70 BP, CAR-309) (Smith, 1985). At Misterton Carr, on the River Idle, peat was forming *c.* 3300-2700 cal BC (4300 ± 100 BP, BIRM-359) (Buckland and Dolby, 1973). These dates correspond with peat initiation in certain areas of the Moors.

However, peat initiation occurred earlier in the river Torne floodplain. Radiocarbon dates from the base of the palaeoentomological site at Rossington indicate peat accumulation at least by 4340-4040 cal BC (5340 ± 45 BP, SRR-6136). Palynological work by Mather (1991) suggests even earlier dates for deposition in the Torne, sometime around 6000-5000 cal BC, which may represent peat accumulation in a separate meander of the river. Other evidence suggests that peat formation may have occurred earlier elsewhere. The base of the channel of the Hampole Beck at Sutton Common, which flowed into the Went at Norton Common Farm, indicates peat formation during pollen zone VIIa (*c.* 5320-3990 cal BC, *c.* 6,300-5200 BP) (Lillie, 1997a). A pollen spectrum from Snaith Ings, east Cowick on the river Aire, suggests that peat formation occurred sometime after the *Ulmus* decline *c.* 4,000 cal BC (*c.* 5,200 BP) (Lillie, 1997a).

There is thus some fairly convincing evidence that floodplain peat, in some areas, may have begun forming sometime *c.* 5000 cal BC, possibly earlier, although in other areas, floodplain, together with mire peat deposition, did not appear to commence until *c.* 3300-3000 cal BC. Peat initiation thus seems to have begun at different times in different localities, and it is possible that certain areas, now obscured by alluvium and warp, may preserve older peat sequences.

11.6 The onset of alluviation in the Humberhead Levels

Peat development in the floodplains developed more-or-less in a stable manner, until peat deposition was terminated by a phase of alluviation. Fossil insect evidence from Rossington suggests that this episode was preceded by a period of increasingly waterlogged conditions. Increased flooding eventually caused overbank alluviation (Buckland and Sadler, 1985). As discussed in Chapter 10, the alluvium is probably late Roman in date.

This episode has been noted in several floodplain deposits associated with rivers in the Humberhead Levels, notably the Torne (Rossington, Chapter 10), The Idle (near Misterton Carr, Chapter 10) and Don (near Sandtoft, Buckland and Sadler, 1985). Stratigraphic investigations by Dinnin (1997b) indicate that these deposits are widespread throughout the floodplains of these rivers. Effects were also felt within the Trent floodplain, where similar deposits have been noted (e.g. Riley *et al.,* 1997; Dinnin, 1997e).

Deforestation and agricultural intensification are thought to have contributed to the late Roman and post-Roman alluviation in the region (Buckland and Sadler, 1985). Palynological (Smith, 1985; Mather, 1991) and fossil insect evidence (Roper and Whitehouse, 1997; Buckland and Sadler, 1985; Chapter 10) indicate that large areas of woodland had been cleared in the Levels by this period. At Rossington, prior to the deposition of the alluvial samples, the fossil insect evidence indicates a cleared landscape, with few areas of woodland and no insects species associated with undisturbed woodland. Pasture areas are indicated by insects associated with grazing animals. In addition, changes amongst the aquatic insects indicate increased levels of eutrophication and sedimentation in the river Torne and its catchment. Similar environmental changes are also evident in the assemblages from Misterton Carr.

Buckland (1979) considered that by the end of the Roman period primary forest on all but the most marginal land had been cleared for agriculture, an impression which is corroborated by the extensive cropmarks of field systems visible in this area. Buckland and Sadler's (1985) investigation of Roman insect faunas from Sandtoft lends further support to this. They suggest that *"By the Roman period areas of river bank must have differed little from the over-managed species-poor fringes of many fenland streams of* *the present day...the evidence combines to imply a mixed farming economy in a wholly cleared landscape, perhaps not too dissimilar from the modern one"* (Buckland and Sadler, 1985, 246).

Agricultural innovation may have made soils more susceptible to erosion (Buckland and Sadler, 1985). It has already been noted that the Roman settlement and use of this landscape appears to coincide with a period of lower water tables. This would have enabled large portions of land to be farmed, whilst the network of rivers and channels would have ensured good irrigation and a mode of transport of produce and goods. However, such increased utilisation of the land appears to have led to soil erosion and this, coupled with renewed sea-level rise, may have impounded freshwater in rivers, causing alluviation. Evidence from North Ferriby, on the Humber foreshore, (Buckland *et al.*, 1990) indicates that alluviation occurred there also. Macklin and Needham (1992) draw attention to the greater role of climate in controlling river sedimentation and erosion than previously believed, with alluviation perhaps occurring during relatively brief periods of abrupt climate shift, characterised by major changes in flood frequency and magnitude.

The neglect of Roman sluices may have exacerbated drainage problems in the Levels (Buckland and Sadler; 1985; Jones, 1995). For instance, the Turnbrigg and Bykers Dykes are artificial waterways perhaps of Roman date (Samuels and Buckland, 1978), although the dates of both these waterways are uncertain (Buckland and Sadler, 1985) and alluviation is not restricted to the managed rivers (*idem.*). Evidence from elsewhere in England and Wales, suggests that drainage of landscapes was occurring during the Roman period, such as in the Fenlands (Phillips, 1970) and in the Gwent Levels (Rippon, 1996).

To date, there has been no attempt to source the alluvium by sediment analysis (e.g. Collins *et al.*, 1997). Dinnin (1997d) suggests that the alluvium probably originates from the Humberhead Levels itself, although Long *et al.* (1998) point out that some of the sediment may have originated from within the Humber estuary and beyond.

11.7 Exploitation of wetland resources in the Humberhead Levels

Limbert (1998) provides a fascinating account of the range of natural products which historically have been collected off the Moors, including plants such as *Eriophorum* spp. (used for bedding), *Calluna* and *Sphagnum*. Edible plants such as mushrooms and *Vaccinium* were also collected. More importantly, the Moors were widely exploited for fishing and fouling. On Thorne Moors, in particular, hunting of duck was particularly popular and duck decoys were constructed across the Moors by enlarging existing bog pools sometime in then 18th and 19th century (Limbert, 1998). Peat also appears to have been removed from the Moors for fuel, possibly from the Roman period onwards (Chapter 7). Beresford's (1986) historical study of Inclesmore indicates that the value placed upon these wetlands as sources of revenue.

Although there is a lack of evidence for human impact upon the insect faunas until a comparatively late date, the range of natural resources available off these wetlands makes it difficult to believe that such areas were not utilised in some form or another by people. Chapter 2 has summarised the wealth of archaeological finds from the area. The fact that the Bronze age trackway on the south side of Thorne Moors was constructed indicates that the area was utilised by prehistoric people, either for passing through or to make use of its many wild resources. Utilisation may have been at a very low intensity for its natural resources, although the wetlands may also have provided a focal point for ritual activities, considering the large number of bog bodies which have been discovered from the Humberhead Levels (e.g. Turner and Briggs, 1986).

11.8 The significance of fire and charcoal within deposits from the Humberhead Levels

The abundance of preserved trees within peats is not unique and has been recorded from many peatland sites, both lowland and upland, in the British Isles (e.g. Black, 1843; Reid, 1913; Andersen, 1967) and has recently attracted renewed research interest (McNally and Doyle, 1984; Gear, 1987; Bridge *et al.*, 1990; Lageard and Chambers, 1993; Grant, 1995; Lageard *et al.*, 1995) (see Plate 11.2 for an example of *Pinus* from Lindow bog, Cheshire). Although most commonly *Pinus* is found, a range of other trees are prevalent. Reid (1913, 1), in his discussion concerning the remains of tree stumps along coasts, remarks, *"The trees are often well-grown oaks, though more commonly they turn to be merely brushwood of hazel, sallow and alder, mingled with swamp-plants"*. Kaland (1986, 26) notes the presence of trees and wood remains at the base of heaths and mires in Norwegian coastal heaths, and comments *"it is important to note that the upper stumps are often surrounded by varying amounts of charcoal, indicating that most of the forest disappeared during fires"*.

On Thorne and Hatfield Moors, evidence for charring is widely distributed across the Moors and, the majority of charred material is associated with *Pinus* and *Betula*. Although antiquarian (*cf.* De la Pryme, 1701) and previous researchers (Buckland and

Kenward, 1973; Buckland, 1993) have suggested that the fire may represent human landnam clearance, there is little evidence to support this idea. Despite extensive surveys of both and Thorne and Hatfield Moors (Whitehouse, 1993 and chapter 4; Dinnin, 1994; 1997b; Boswijk, 1998), there has been no convincing evidence for anthropogenic forest clearance, although the period when the fires were occurring overlaps with late Neolithic and early Bronze ages, when settled communities were present in the landscape (see Chapter 2). The absence of direct evidence for human activity on the mires, coupled with the extensive areas which appear to have been burnt, suggests that such fires may have been natural in origin, perhaps a result of lightning ..

The fossil insect evidence indicates that much of the woodland growing on the mires was moribund and rotting prior to fire, and it is likely that increasingly wet conditions contributed to the demise of the woodland. Peat initiation had already commenced, at least locally, and this, together with the accumulation of combustible material, may have been a key factor in ensuring that during periods of seasonal drought the mire would have been extremely flammable. However, on at least one occasion, noted at Blackwater Dike (Thorne Moors), *Pinus* woodland appears to have expanded in response to local fire on the mire surface.

Boswijk (1998) attempted to address the question of whether fire was caused by anthropogenic activities or natural causes. She used the tree ring data to attempt to identify multiple fire events. If fires are detected, it is possible to determine seasonality of fire events through dendrochronological studies, which can be used to test hypotheses about the respective roles of climate versus humans in controlling fire regimes (Ortloff, 1996). However, Boswijk was not able to identify such events on Thorne Moors and concluded that there was insufficient evidence to suggest an anthropogenic cause to the fires, suggesting that they were rare, natural occurrences.

The evidence from Thorne and Hatfield Moors and elsewhere suggests that fires were a common event on *Pinus* mires, and may indicate that such episodes played an integral part in the development of peat bogs and their continued evolution. *Pinus* remains are consistently associated with charcoal deposits in a number of different mire locations and in profiles (e.g. northern Scotland, Gear, 1989; Sweden, Ågren and Zackrisson, 1990; Whixall Moss, Grant, 1995). In addition, a close correlation between *Pinus* pollen values and macroscopic charcoal has been found at some sites (O'Sullivan 1991; Little *et al.*, 1996). On Red Moss, Aberdeenshire, a thin layer of charcoal was noted in the stratigraphy directly associated with an exposed pine. Charcoal was only associated with this part of the sequence and there was no evidence of burning of the peat layers (author's own observations). This indicates that the event noted on Thorne and Hatfield Moors is not unique and suggests that such events, although rare, were not uncommon. The occurrence of fire may also have been more frequent if a more continental weather pattern prevailed during the mid-Holocene.

Fire has long been recognised as an important component within boreal forests (e.g. Zackrisson, 1977). There appears to be a strong association between *Pinus* and fire, with its flammable resins (*contra* Bennett, 1995). For instance, *Pinus* regeneration appears to benefit from natural and man-made disturbance; early records repeatedly refer to large areas of regeneration after felling and burning (Carlisle, 1977; Uggla, 1958, 100) with the greatest regeneration success following fires. The picture thus emerges of *Pinus sylvestris* being at least partially fire-dependent under natural conditions (Bradshaw, 1994; Steven and Carlisle, 1959, 84-5; Carlisle, 1977; Engelmark, 1987, 322). This is less extreme than some North American species which require heat to open their cones, but may resemble the situation of such species as Red Pine (*Pinus resinosa* Ait.) and White Pine (*Pinus strobus* L.), which require fire to create the best regeneration conditions in the vegetation and in the soil (Carlisle, 1977). Studies in Sweden (Uggla, 1958, 99; Engelmark *et al.*, 1994) indicate that forest fires can burn for many weeks, and that most forests in northern areas of the country have been devastated by fire, with charcoal particles from ancient forest fires being very common in the humus layer. Fire also appears to facilitate the entry of *Betula* as a pioneer tree into burnt areas (Uggla, 1958, 100). Recent fire control may explain the decline of *Betula*-woods as a component within native Scots pinewoods (Gimingham, 1977), although anthropogenic disturbances are likely to have played a major role in the decline of this species. Pollen diagrams (Steven and Carlisle, 1959; O'Sullivan, 1973; 1977) indicate that *Betula* was formerly a much more important component of these forests prior to exploitation, as it is today in comparable woodlands in Scandinavia (Gimingham, 1977).

The insect evidence from the raised mires of Thorne and Hatfield and the floodplain deposit from Rossington contain many pinicolous faunal elements which are typical of these boreal forests. Whilst not suggesting that these forests were boreal, they appear to share many similarities, including, perhaps, the importance of fire within these ecosystems (e.g. Uggla, 1958; Heinselman, 1973). The decline and demise of some pyrophilous insect species would support this (see Chapter 12).

Whilst it may be easy to accept arguments regarding the flammability of *Pinus* woodlands, it is less easy to accept the notion that British deciduous woodland may have burnt. However, there is tentative evidence from Thorne and Hatfield Moors for charred *Quercus* trees. The *Quercus* from Tyrham contained charcoal, although this may have burned some time after its death. On the south side of Thorne Moors Buckland and Kenward (1973) noted a burnt *Quercus* close to the Bronze Age trackway. This burning was interpreted as being due to anthropogenic activities. However, other areas of burnt *Quercus* have been noted on Thorne Moors, although again, burning may have occurred prior to burial within the peat as a result of fires on the mire surface. Sheppard (1903, 156), writing about excavations carried out on the Albert Docks, Hull recounts that *"Trunks of oak trees, some of them 60 feet long, were scattered through the peat, and had evidently fallen where they grew"*. Associated with some of these trees was charcoal. Bradshaw (1993) provides an account of a deciduous forest in Sweden, including *Tilia*, *Ulmus* and *Corylus*, which appears to have burnt after a series of massive fires some 700 years ago, causing the forest to become dominated by boreal communities. Palaeoecological studies in eastern United States suggest that fire has actually contributed to the dominance of *Quercus* forests (Abrahams, 1992). Whilst recognising that different species are involved in the American example, it does indicate that burning of these types of woodland can occur. Although limited, there is thus some evidence that deciduous woodland does burn naturally, under certain circumstances.

However, much of the current literature suggests that British mixed deciduous woodland cannot ignite. Rackham (1986, 69) states that *"native woods (except pinewoods) will not burn"* and suggests that trees have to be felled, cut up and stacked before burning (Rackham, 1986, 72). Peterken (1981), however, points out that trees are divided into tolerant and intolerant genera. Intolerant species such as *Betula*, *Fraxinus*, *Pinus* and *Quercus* are more susceptible to fire, and forests of such species are more easily set on fire by lightning (Peterken, 1981).

The fossil insect evidence suggests that many of these undisturbed deciduous woodlands contained abundant amounts of dead wood and plant matter. The assumption that deciduous forests do not burn appears to be based upon an incomplete knowledge of the structure of many of these wildwoods during the early and mid-Holocene, in terms of fuel availability, dryness and possible causes of ignition. In addition, fire regimes are dependant upon local weather (e.g. precipitation, wind), large scale regional weather (e.g. lightening, occurrence), global climate (e.g. El Nino events), topography, geology, and relief, amongst other things (Swetnam, 1990), some of which are likely to have fluctuated in the past.

The assumption that natural fire did not occur amongst Britain's deciduous woods does not take into account that fact that climate and weather, which have a direct effect upon *the firing of a woodland, may have been different in the past*, particularly during the early and mid-Holocene. If climatic conditions were more continental, perhaps warmer and drier, forest fires may have been more frequent, although any fire cycle is likely to have operated on a centuries or even millennial scale. Lightening is frequent during periods of high pressure (anticyclones) that are more typical of "continental-type" climates (Heinselman, 1973; Tolonen, 1985). In continental Europe, forest fires can be common in deciduous woodland (authors' own observation). There is thus little convincing evidence to support the idea that deciduous woodland in Britain was not subject to periodic burning, and at the very least, this lack of evidence should be taken to promote new research. As Clark *et al.*, (1989) point out, many researchers have ignored "natural fire" as an important factor because of the absence of existing "undisturbed" landscapes and the *assumed* low flammability of deciduous forests.

The possibility that early and mid-Holocene British forests may have burnt naturally suggests that the interpretation of charcoal within mire deposits as a possible anthropogenic indicator should be at least be re-evaluated. Microscopic charcoal particles within peat deposits have often been *interpreted as being the result of off-site* archaeological activities (e.g. woodland clearances, domestic fires, burning vegetation to encourage game), becoming incorporated into deposits as air-borne particles (e.g. Bennett *et al.*, 1990; Mather, 1991). Whilst not suggesting that charcoal is always the result of natural fires, it is important to consider natural as well as anthropogenic causes to such events. In addition, the evidence suggests that fire is an important component within the mire ecosystem, as the common occurrence of charred *Calluna* seeds from deposits on Hatfield Moors indicates (whilst some of this material came from the upper sections of the peat and could have become incorporated into deposits because of management burning, its frequent occurrence *throughout* the profile would indicate other factors were involved). Charred mire plant material has been identified at a number of sites (e.g. Foster *et al.*, 1988; Kuhry, 1994; Korhola, 1992) as well as abundant charcoal (Foster and Fritz, 1987, Mäkilä, 1997). Mäkilä (1997, 6) found evidence for regular burning on a mire in southeastern Finland and suggests that fire affected not only the marginal parts of the mire, but also the wettest areas, mainly on the driest hummocks. He suggests that the hot dry summers of the warm periods of the Holocene caused numerous peat fires (Mäkilä, 1997). The presence of charcoal in many mire deposits thus raises the question of whether fires play an integral part in the development and evolution of peat bogs and whether there are links between the fire modified hydrology of a catchment with peat initiation and development.

CHAPTER 12: PARADISE LOST? THE DEVELOPMENT AND DECLINE OF THE BRITISH ENTOMOFAUNA AND ITS ASSOCITED HABITATS

> Carabids are beetles of ground.
> So spots where carabids are found
> are grounds for inferring
> That there they're occurring.
> This circular reasoning is round.
>
> Without wings they're more apt to stay there.
> But the winged may take to the air
> Dispersing in myriads
> Though Tertiary periods.
> We know they all started, but *where*?
>
> ("Homage to P.J.Darlington, Jr.", by John M. Burns, in Erwin *et al.*, 1979.)

12.1 Introduction

The fossil insect evidence from the Humberhead Levels highlights the decline and extirpation of many elements of the British fauna, in particular those associated with forested habitats. Palynological evidence for the disturbance of primary woodland in Britain is abundant, starting as early as the Mesolithic (*c.* 10,000-5,000 BP) (e.g. Williams, 1985; Caseldine and Hatton, 1993; Edwards, 1996; Simmons, 1996; Edwards and Whittington, 1997), although Tipping (1994, 16) points out that some of these episodes of "Mesolithic activity" may have been generated by a mixture of anthropogenic and autogenic woodland processes. However, by the late Iron age (about 2,000 years ago), in many areas, substantial areas of the British landscape appear to have been cleared and only fragments of primary woodland still survived (Robinson, 1981; Buckland and Sadler, 1985; Greig, 1996). The progressive loss of woodland has had a significant impact upon the landscape, and its effect upon the terrestrial invertebrate fauna was immense, leading to the extinction of numerous saproxylic beetles and a reduction in the range of many others. The effect of deforestation on the aquatic environment resulted in a change in the sedimentation regimes in major rivers, and drastically altered communities of water and riparian beetles. Thus, human activities, particularly over the last 5000 years, have had a significant impact upon the British landscape and its associated biota.

This chapter discusses the nature of *Urwald* and the establishment of its associated entomofauna. Discussion then follows upon the evidence from the Humberhead Levels and illustrates the response of beetles during the transition from *Urwald* forest to "culture-steppe" (*sensu* Hammond, 1974). The significance of the non-British and rare species recovered and the wider implications of the faunas are discussed.

12.2 The nature of Holocene *Urwald*

Rapid climatic warming at the end of the last glaciation enabled tree taxa to colonise Britain at the beginning of the Holocene, at varying rates of expansion. Each taxon displayed individual patterns in terms of its arrival area, directions, timings, rates of spread and attainment of broad-scale range limits (Birks, 1989). Palynological evidence suggests that by *ca.* 5,000 years ago, there were extensive tracts of *Tilia*-dominated woodland in lowland areas of England and Wales, with *Quercus* in the north and west, giving way to *Betula* and *Pinus* in the north of Scotland (Bennett, 1988).

These old growth forests were structurally complex and rich ecosystems, characterised by significant numbers of huge, long-lived trees. The canopy was multi-layered, composed of crowns of trees of different types and ages. Dead wood was abundant as both standing and fallen trunks. Every component of the forest, from the crowns to the roots buried in the soil, would support, and was supported, by a great web of organisms. Harding and Rose (1986) have suggested that *Urwald* was closer in structure to pasture woodlands, with their mosaic of different habitats and partially open structure, than woodlands such as plantations, which are densely planted. At the present day, old, naturally developed woodlands probably do not reflect the structure of these wildwoods, as the lack of grazing animals has allowed then to have become rather dense.

Semi-permanent open spaces would have been regularly created by natural processes such as wind blow and the death of trees. Insect attack and pathogens would have affected substantial areas of woodland, including defoliation and extensive tree damage (*cf.* Patterson and Backman, 1988). Such episodes would have opened up the canopy of the woodland, creating clearings, and generating a build-up of fuel upon the forest floor, thus making the forest more susceptible to fire (Danks and Foottit, 1989). In unlogged forests, fire plays an important role in eliminating forest stands which are plagued with overstocking, excessive fuel accumulation, and pest-infested and diseased trees (Szwecki, 1987). Climate and weather also have a direct effect upon the incidence of fire (*cf.* Saari, 1923). Early Holocene and later sediments often contain abundant charcoal indicating frequent fires (Patterson *et al.*, 1987; Patterson and Backman, 1988; Huntley, 1993). These natural processes would have created areas of clearings within woodlands, long before human activities had any impact upon the forest. Some of these may have been maintained as substantial, relatively permanent, openings by activities such as natural grazing (Buckland and Edwards, 1984).

These woodlands supported a distinctive invertebrate population of *Urwaldtiere* (*cf.* Palm, 1951). Although Pearson (1966) and later Hammond (1974) suggest that the British fauna had achieved its present characteristics by *c.* 7000 uncal B.P. (*c.* 6000 cal BC), including those southern species no longer found in the British Isles, Osborne (1997a) points out that by 9500 BP a thermophilous fauna had already established itself in the English Midlands, suggesting that development towards a closed forest ecosystem was already underway (Osborne, 1974a). *Betula* and *Salix* appears to have been abundant, and there was already a fauna associated with dead wood, with species such as *Sinodendron cylindricum* (L.), *Bitoma crenata* and cerambycidae like *Rhagium mordax* (Deg.) and *Aromia moscata* (L.). By about 9000 B.P. some of the *Urwaldtiere* such as *Melasis buprestoides* (Osborne, 1980) were present, a species typical of early-Holocene assemblages. As tree species expanded from Europe and habitats became more diverse, this fauna expanded over the next few thousand years (Osborne, 1997a), including a number of specialist saproxylics which no longer live in Britain.

Table 12.1 shows the earliest as well as the most recent fossil records for the extirpated species recovered from fossil deposits. It is difficult to know exactly when these species arrived in Britain because of the paucity of sites covering the earlier part of the Holocene. For instance, the Old Forest species *Dromaeolus barnabita* was already present by *c.* 8240-6290 BP at Bole Ings, Nottinghamshire (Dinnin, 1997e), together with a range of other species indicative of primary forest. Today this species is extirpated and is considered endangered in Sweden because of clear-cutting and the removal of old, hollow trees from woods and parks (Ehnström *et al.,* 1993). However, increased diversification of saproxylics communities seems to have occurred *c.* 7000 uncal BP (*c.* 6000 cal BC) (Brayshay and Dinnin, *in press*).

12.3 From *Urwald* to culture steppe: evidence from the Humberhead Levels

British forests reached their maximum development by the mid-Holocene, 5000 years ago. However, by about the mid-late part of the Holocene (*ca.* 4000-2700 BP), many *Urwald* assemblages were showing the effects of forest clearance (Osborne, 1965), and were being increasingly replaced by elements of "culture-steppe", insects associated with cleared landscapes and pasture.

For example, at Runnymede, Surrey, late Neolithic deposits are characterised by an insect fauna with a strong *Urwald* element. By the late Bronze age, however, the insect fauna reflects a largely agricultural landscape (Robinson 1991). At Wilsford, *c.* 1880-1430 cal BC (3330 ± 90 BP, NPL-74) Osborne (1969) records a fauna which indicates grazing animals in an almost tree-less landscape. Transitions from forested to cleared landscape have been observed at other sites in Britain (e.g. Girling, 1989) with the result that by the Iron age mature woodland beetle species appear to represent an insignificant faunal element (Girling, 1979b; 1982b; Chowne *et al.*, 1986; Robinson, 1981b, 1993). Natural forests may have survived in some areas until about 3,000 BP (Speight, 1989; Harding and Alexander 1994), but by about 1000 years ago it is doubtful whether anything more than patches of secondary forests remained (Greig, 1982). Today forest cover is reduced to eight percent of the landscape, over half of which is in plantations of non-native tree species (Warren and Key, 1991), although there has been a recent modest expansion of lowland woodlands composed of native tree species as a consequence of agricultural reform (Dennis, 1997).

Much of the fossil insect work carried out as part of this research and from elsewhere indicates that Britain has lost a large portion of its original old-growth woodland Coleoptera, particularly the saproxylic species, along with the loss of primeval and semi-natural forests and woodlands. The disappearance of many of these species have been linked to the use of forest resources for fuel, fodder, wood for construction and in particular, the removal of dead wood (*cf.* Buckland, 1979; Girling, 1985; Buckland and Dinnin, 1993), as well as clearance of *Urwald.*

Thorne and Hatfield Moors represent the most recent post-glacial sites which display many elements of this *Urwaldrelikt* fauna, suggesting that undisturbed woodland persisted in this area of wetland for a considerable period, long after woodland had been cleared elsewhere. This vast area of agriculturally unusable wetland probably secured its survival, ensuring an "ecological island" (*cf.* McArthur and Wilson, 1967), which was buffered from external environmental influences. It is probable that similar "islands" existed elsewhere, particularly on areas of developing wetlands such as in the Somerset Levels and Cheshire Mosses.

The pollen and insect data from the Moors highlight the importance of habitats associated with *Pinus*, *Betula* and *Quercus*. Whilst *Quercus*-dominated woodland grew on the mires initially, *Pinus* and *Betula* superseded this early woodland. *Quercus*-dominated mixed deciduous woodland probably continued growing on the higher ground around Thorne and Hatfield Moors (Smith, 1985), with *Pinus*-dominated woodland along the margins of the mires. At Rossington and Misterton *Pinus*-woodland heath appears to have been an important habitat on the higher sandy areas above the floodplain. Extensive areas of heath are also indicated on some of the 19th century maps associated with the area. The importance of *Pinus* in the Humberhead Levels' landscape is illustrated in the vast range of species associated with this tree (section 12.8).

The mire assemblages are notable for their absence of beetles associated with *Tilia*, which was an important component within British lowland forests of this period (Greig, 1982). One species in particular, *Ernoporus caucasicus*, is found in most mid-Holocene forest insect assemblages (Buckland and Dinnin 1993; Dinnin, 1997e). However, it has been found in roughly contemporaneous floodplain deposits from Thorne Waterside, west of Thorne (> 3020-2620 cal BC, 4230 ± 100 BP, BIRM-358) (Buckland, 1979), and is abundant in the samples from Misterton Carr (> 3300-2700 cal BC, 4330 ± 100 BP BIRM-359) (Buckland and Dolby 1973; Osborne 1978 and Chapter 10). The presence of *E. caucasicus* indicates *Tilia* in the Torne floodplain at Rossington at about this time, although disappearing sometime after *c.* 1690-1450 cal BC (3290 ± 45 BP, SRR-6131), which is roughly analogous with Turner's (1962) primary *Tilia* decline (*c.* 1750-1100 cal BC, 3170 ± 115 BP, Q-481). In contrast, at Bole Ings, in the Trent valley a few km south of Misterton, this scolytid seems to disappear sometime after *c.* 2140-1740 cal BC (3570 ± 70 BP, BETA-75271) (Dinnin, 1997e), suggesting *Tilia* may have been cleared from the landscape in the Trent valley earlier than in the Humberhead Levels.

The present and former distribution of this scolytid suggests that it is a relic of the former dominance of *Tilia*-woodland across much of lowland southern England and the Midlands. Its decline, from a former widespread distribution to its present occurrence on a few sites, probably reflects the decline of its host due to preferential use of this tree for wood and fodder. *Tilia*, together with *Ulmus*, are palatable to stock - the bark and leaves were once widely used in Europe as fodder, and the decline of these trees may be related to this (Turner, 1962). *Ernoporus caucasicus* appears to disappear from the fossil record by the early Bronze age, by which time the frequency of the tree had already been severely reduced (Buckland and Dinnin, 1993).

The deposits from Rossington highlight the importance of *Alnus* and its associated fauna on the Torne floodplain. This is illustrated by the frequent occurrence of *Chrysomela aenea* and the RDB1 species *Agelastica alni*. *A. alni* is now presumed extinct in Britain (Harde, 1984), although there are 19th century and fossil records suggesting its former wider occurrence. The continued presence of this beetle's food source, *Alnus*, cannot explain its contraction, but, as Robinson (1993) points out, neither can climate change, given the 19th century records for this species. He suggests that this species may thrive only in extensive, undisturbed *Alnus*-woods. *Chrysomela aenea,* which was very common in many of the deposits from the Humberhead Levels is not a particularly common species today (Skidmore, *pers. comm.*, 1995). The decline and contraction in both these species' distributions probably reflect not only the lack of extensive, undisturbed *Alnus* woodlands, but also the decline in *Alnus* coppice, which was formerly more widespread (Edlin, 1966), as well as the decline of floodplain woodlands due to increased drainage (see section 12.10). *Alnus* carr was widespread across the floodplains of the rivers Torne and Idle floodplain at Rossington and Misterton (Chapter 10) and in the northern part of the Levels at Sutton Common (Parker-Pearson, 1997a).

The insect evidence suggests there was thus a gradient across the Humberhead Levels landscape, from *Tilia-Alnus* dominated deciduous woodland on the floodplains, to *Quercus*-dominated mixed deciduous woodland, together with *Pinus,* on the Sherwood Sandstone and sandy drift deposits. *Pinus-Betula* woodland grew around the margins of the Moors and periodically invaded the mire surface. Areas of *Pinus-Calluna* heath probably also grew on exposed areas of wind-blown sands.

Off the ecological islands of the Moors, the faunas indicate that woodland clearance had intensified by *c.* 1500 cal BC at Rossington, and many of the rare species of Coleoptera had disappeared from the record by this period. On Thorne Moors and Hatfield Moors, however, species such as *Prostomis mandibularis, Mycetina cruciata* and *Tenebrioides fuscus* continued living in *Urwald* forest. Much of the Torne floodplain was probably cleared of primary woodland, although patches of primary woodland remained. The insect evidence indicates areas of grassland and included a variety of species which are often associated with waste, cultivated and open ground. The aquatic insects also indicate higher amounts of sediment entering the river system, possibly caused by clearance and agricultural activities upriver. By the Roman period, much of the surrounding area was cleared, although some local regeneration of woodland seems to have occurred.

During the latter part of the Roman period, the floodplain was becoming increasingly waterlogged, with the eventual deposition of alluvium, partially in response to higher sea-levels, but perhaps more importantly because of soil erosion due to agricultural intensification and innovation (*cf.* Buckland and Sadler, 1985). The faunas from Rossington show very effectively some of the changes which have affected the British entomofauna. Similar changes are evident amongst the faunas from Sandtoft, east of Hatfield Moors (Buckland and Sadler, 1985), discussed previously (section 11.6).

At Misterton Carr, the landscape appears to have been less subject to clearance, until later in the prehistoric period, although it is difficult to ascertain exactly when clearance occurred due to the lack of dates for the top part of the sequence and the limited nature of the faunal list. Here too, alluvium was deposited in the Idle floodplain. The Iron age landscape at Sutton Common, *c.* 750-390 cal BC (2370 ± 50 BP, GU-5524) (Parker Pearson, 1997a) indicates a largely cleared landscape, with little evidence for primary woodland. Further south, in the Trent valley, pollen and insect evidence suggests that relatively undisturbed forest survived on the marginal floodplain soils until sometime between 2140-174 cal BC and > 1040-800 cal BC (3570 ± 70 BP, BETA-75271 and 2750 ± 60 BP, BETA-75269) (Brayshay and Dinnin, *in press*).

Despite the impression of a largely cleared landscape in the Humberhead Levels by the end of the Roman period, excavations at the moated site at Cowick (Hayfield and Greig 1989), five km west of Thorne Moors, suggests that a relic *Pinus* and ancient woodland fauna survived into the medieval period in a landscape of pasture woodland. Wagner (1997) recovered several *Urwaldrelikt* species such as *Teredus cylindricus* and the *Pinus*-loving *Rhyncolus ater* from another moated site, at Wood Hall (Womersley, North Yorkshire) 15 km west of Cowick in samples spanning *c.* 1400 to the 18th century. The species may have been protected by the Forest Laws which covered the area and suggest that despite widespread clearance in the Roman period, vestiges of ancient woodland remained in the Humberhead Levels. Other extinct species may have survived in refugia until this period. Today Lindholme Island contains many faunal elements of pasture woodland (Skidmore, *in press*) and it is possible that some of the *Urwaldrelikt* species may have survived into the medieval period and beyond in this area.

The cooler climate of the post-medieval "Little Ice Age" (Grove, 1988) may have had a detrimental impact on these faunas, although Wagner (1997) suggests that there is little convincing evidence to suggest this event had a major impact on the British insect fauna. She points out that there has been a notable absence of "culture-steppe" assemblages studied, covering the last *c.* 2000 years. Insect faunas from Wood Hall span the "Little Ice Age" and show no evidence of this episode (Wagner, 1997).

12.4 Noteworthy species records: non-British species

This section presents information on the non-British species that have been recovered from the deposits studied in the Humberhead Levels. Although other non-British species have been recovered from the Levels, they have been reviewed previously in detail by Buckland (1979) and Whitehouse (1993, 1997a) and these details are not included, although their evidence is discussed below. There is one exception to this (*Buprestis rustica*), as a proper account of this species' distribution and biology has not been published. The complete list of extirpated Coleoptera from Humberhead Levels is presented in Table 12.2, (a total of 18 species), together with details of other fossil records for the species.

The distribution maps (Figures 12.1-12.14), provide an indication of the present distribution of species, as well as fossil find-spots of species. Information concerning many of these species is very incomplete, and absence of records from an area may not indicate a species' absence. In many cases, the data are dependant upon records from the last century, and is positively correlated with those areas most studied by entomologists. In many cases, the biogeographical patterns of many saproxylic invertebrates are not well-known (McLean and Speight, 1993).

12.4.1 Pterostichus angustatus

Pterostichus angustatus was recovered from LIND B, Hatfield Moors, in deposits dated to *c.* 2700-2350 cal BC (3990 ± 60 BP, BETA-91800). This species is not extirpated and has a Notable B status, but is included in this section as it has been considered an established immigrant since *c.* 1900 (Hyman, 1992), although this is clearly incorrect given its fossil record. Early records are from London and south Yorkshire, spreading through eastern England, although there are no northern Welsh or south-western records (Luff, 1998). It has spread northwards as far as Carlisle and Tyneside, but there are only three records from Scotland, and these are not associated with the Caledonian pinewoods (Luff, 1998). Much of information on the biology of this species would suggest that it is mainly associated with lowland situations and the lack of lowland plantations may explain its limited range in Scotland (Skidmore, *pers. comm.*, 1998). The occurrence of *P. angustatus* as a fossil is very important in biogeographic terms as it confirms the native status of this species. Although the size of this carabid suggests that it is unlikely to have been overlooked by collectors, it is just possible that this species has been overlooked until recently. There is no prior record of this species as a fossil, so it is difficult to know whether the present population of this species is a re-introduction or an overlooked population.

The biology of *P. angustatus* is interesting as it is typically found on burnt ground, in particular sandy heaths (Lindroth, 1974; Wikars, 1992; Luff, 1998). Lundberg (1984) suggests it is almost exclusively associated with burnt wood, and places it in the same category as the pyrophilous *Melanophila acuminata* Deg. It also appears to favour *Pinus*-woodlands (Koch, 1989, Bilton, 1991). It is not difficult to understand why this species was present on Hatfield Moors, with its *Pinus*-heath, subject to periodic burning. This species is today reasonably common on Hatfield Moors (P. Skidmore, *pers. comm*, 1998). There does not seem to be any apparent reason for this species' contraction in range since burnt heath is not likely to have been a particularly scarce resource in the past, although today it is a habitat much reduced. However, this species is considered to have declined in Sweden because of forest fire fighting, and the suppression of fire may be an important factor in its decline (Ehnström *et al.*, 1993). Its apparent re-expansion since the beginning of this century suggests that conditions have once again become favourable, perhaps due to frequent prescribed management burning of heath, peatlands and heather moorlands (*cf.* Gimingham, 1977), and very possibly the expansion of conifer plantations.

12.4.2 Buprestis rustica

A complete individual of the jewel beetle, *Buprestis rustica,* L. was recovered from its pupal chamber in a fossil *Pinus* during fieldwork on the northern part of Thorne Moors (P. Skidmore, *pers. comm.*, 1994). Although undated, it probably lived sometime within Boswijk's (1998) *Pinus* chronology for Thorne Moors, which would date the specimen to between 2921-1489 BC. The larvae of this rare species live in dead *Abies* and *Pinus*, where their development takes two years. The adults are frequently found from June to September, on conifers in the hot midday sun, often in large numbers (Harde, 1984). Lundberg (1984) recovered this species from burnt woodland, although he does not regard it as a fire species.

The distribution of *B. rustica* (Figure 12.1) includes central and northern Europe, the northern part of southern Europe, as well as the Caucasus and Southern Siberia (Harde, 1984). More specific records suggest southern France, Austria, Sweden and Germany (Gaubil, 1849); Finland and Russia (Mannerheim, 1836-37); the northern part of Finland (Zetterstedt, 1828); Switzerland (Gistl, 1829) and across the northern provinces of Italy (Porta, 1929).

12.4.3 Isorhipis melasoides

The only secure identification of this species as a fossil came from Misterton Carr, where it occurred frequently thorough the sequence. Fossil material from Hatfield

Moors could only be identified as *Isorhipis melasoides* or *Melasis buprestoides*, its close associate. The Misterton specimens are dated to after 3300-2700 cal BC (4330 ± 100 BP, BIRM-328) (Buckland and Dolby, 1973). This species has also been recovered from Thorne Moors dated to 1400-900 cal BC (2980 ± 100 BP, BIRM-337), West Heath Spa, Herts (Girling, 1989), 4030-3820 cal BC, and from the Somerset Levels (Baker site, *c.* 2500 cal BC [Girling, 1980]).

This beetle is associated with Old Forests, often in dry *Fagus* (Reitter, 1911), although there are also records from *Carpinus, Tilia, Ulmus, Quercus* (Muona, 1993), as well as with *Alnus* (Buckland, 1979). Horion (1953) suggests that it is restricted to areas away from the western seaboard and Mediterranean, and that the species has a discontinuous east-west distribution. It is absent from Scandinavia. Its distribution suggests that it is relatively thermophilous (Figure 12.2), although its absence from areas of central Germany seems to indicate that old established forest is a necessary component of this species' ecology (Buckland, 1979).

Although this species' preferred host is *Fagus*, there are no species which are exclusively phytophagous on *Fagus* present at Misterton. However, Mather (1991) records the presence of *Fagus* in his zone 2b at Rossington, which is dated from *c.* 3800 cal BC to 1300 cal BC (see Figures 2.1 and 10.4). The presence of *Rhynchaenus fagi*, a weevil which is phytophagous on *Fagus*, from deposits on both Thorne and Hatfield also indicates the presence of this tree. The dates of the Hatfield record are *c.* 1320-1030 cal BC to 1000 cal BC (HAT 4, assemblage zone 2) and the Thorne fossil dates from between 3444-2445 BC (Blackwater Dike). This weevil has also been recovered from Sutton Common, in the Levels, dating to *c.*750-390 cal BC (2370/60 ± 50 BP, GU-5524 and GU-5525) (Roper and Whitehouse, 1997). This evidence suggests that *Fagus* was present within the wider landscape and could have hosted *I. melasoides,* although it may have been living on other deciduous trees. On Thorne Moors it was dug out of its pupal chamber in *Alnus* (Buckland, 1979). Perhaps more interestingly, the pollen and insect evidence from the Humberhead Levels indicates the presence of *Fagus* in the landscape considerably earlier than previously thought. Birks' (1989) isochrone maps suggest that *Fagus* did not reach this area until about a 1000 years ago.

I. melasoides' close associate, *Melasis buprestoides* occurred frequently at Hatfield Moors and is today no longer found north of Yorkshire (Dinnin, 1993), yet it has been identified from an Iron Age structure in Scotland, near Kilmarnock (Buckland, 1993).

12.4.4 Tenebrioides ?fuscus

The ostomid *Tenebrioides fuscus* was recovered from HAT 4 (Hatfield Moors) and dated to between *c.* 1320-1030 cal BC and 1000 cal BC (2960 ± 45 BP, SRR-6124). This is a first British record for this species. The identification of this fossil remains tentative, since a named specimen could not be compared with the fossil. It was compared with its nearest species, *T. mauretanicus*, but key characteristics quoted in Vogt (1967a) suggest the fossil is not this species. However, two points are worthy of consideration. Firstly, *T. fuscus* was relatively recently viewed as a synonym for *T. mauretanicus* (Junk, 1910). In consequence, much of the 19th and early 20th century literature lists *T. mauretanicus* as the single species of this genus (e.g. Gistl, 1829; Dejean, 1834-35; Gaubil, 1849; Marseul, 1857; Rupertsberger, 1880; Reitter, 1911; Horion, 1953). Goeze (who first described *T. fuscus* in 1777) lists both *T. mauretanicus* as well as *T. fuscus*. He indicates that the original description came from a publication by Geoffroy (*Histoire abregee des Insectes…*), sometime before 1754 (Goeze, 1777). However, at a subsequent point, nomenclature of this species became confused, although Vogt (1967a) recognised the existence of two separate species, presumably having gone back to the original descriptions. This nomenclatural confusion means that it is very difficult to obtain information about this species. The fact that *T. fuscus* remained unlisted in so many European catalogues of the last century, at the height of Coleopteran collecting, might suggest that this species was already extremely rare.

Vogt (1967a) described *T. fuscus* as an "*Urwaldrelikt*", found in soft rotten wood and under bark, especially in primary woodland areas and old parks, also in floodplain woodlands. It prefers deciduous tree bark (especially *Quercus,* but also *Fagus, Aesculus, Ulmus, Populus* and fruit trees) on fungoid trunks and branches, also in rotting wood, wood mould and in *Stereum purpureum* (violet layer fungus) (Koch,1989). It is recorded in southern and central Europe, everywhere in Germany as far north as Hanover and Brandenberg, where it is rare. It could also be present in France, as the original descriptor of the species was French (Geoffroy). The only recent record of this species is from Czechoslovakia (Gottwald, 1970). It is not present in Fennoscandia. Figure 12.3 shows the distribution of *T. fuscus*.

12.4.5 Cryptolestes corticinus

The Cucujid *Cryptolestes corticinus* was recovered from deposits on Hatfield Moors in deposits dated to *c.* 2000 cal BC. It has been previously found by the author on Thorne Moors (Whitehouse, 1993) in deposits dated > 3350-3100 cal BC (4515 ± 70 BP, CAR-232). This species lives under the bark of *Picea* and *Pinus* (Reitter, 1911; Freude *et al*, 1983), where it is a predator on larvae of Scolytidae (Sippola, *pers. comm.*). In Fennoscandia and the Baltic States, it is distributed everywhere and is fairly common (Sippola, *pers. comm.*), although it is rare in Germany (Reitter, 1911). It is also recorded in Italy (Porta, 1929). Figure 12.4 shows the current distribution of this species.

12.4.6 Pycnomerus tenebrans

This species was recovered from the sequence at Blackwater Dike, Goole Moors, dated to between 3444 BC and 2921 BC (dendrochronological dates). It has also been recovered from roughly similar-dated deposits at West Heath Spa, Herts (Girling, 1989), Minsterley, Salops (Viib, Osborne, 1972) and Stileway, Somerset (> 4470 ± 70 BP, 3360-2920 cal BC (Girling, 1985). The Stileway and Thorne Moors record are more-or-less contemporary and present the latest fossil dates for this species. These records suggest that the beetles once occurred widely across Britain and there is also an interglacial record of this species from Lincolnshire (Girling, 1985). This beetle is a relict species particularly of old forests, with a rare and sporadic distribution (Dajoz, 1977), generally found under the rotting wood of old trees, particularly *Quercus* (Horion, 1962).

Dajoz (1977) provides a summary of its distribution (see Figure 12.5): France (south of the Nantes forest and Alsace); Switzerland; Germany (in the south and the centre); Austria (western areas); Czechoslovakia; Hungary; Romania and Translyvania; Bulgaria; the estuary of the Kamcija on the shore of the Black Sea; Croatia and Bosnia; Italy (in the north and Sicily and Sardinia); Greece (island of Euboia and in the Peloponnese); Portugal. Koch (1989) suggests that it not found in alpine regions or northern central Europe, which may suggest that the species has a minimum temperature requirement.

12.4.7 Prostomis mandibularis

This species has been previously recovered as a fossil from Thorne Moors (Buckland, 1979), dated to 1390-1060 cal BC (2980 ± 100 BP, BIRM-337), and was found on Hatfield Moors during this research. It was found at HAT 3, dated to > 3350-3030 cal BC, (4480 ± 45 BP, SRR-6119) and from the *Pinus* woodland at Tyrham, dated to between 2921-2445 BC. It has also been recovered as a fossil associated with the Neolithic Sweet Track, in the Somerset Levels (Girling, 1984a). More recently it has also been found associated with a bog trackway in southern Ireland, dated to 1440 BC (O' Reilly, *pers. comm.*, 1997). The Thorne and the Irish records indicate that the insect was still living in certain areas of the British Isles *c.* 1400-1000 cal BC.

Although on Thorne Moors it was recovered in large numbers associated with the Bronze age trackway, probably living in rotting *Quercus*-wood, on Hatfield Moors it seems to have been living in *Pinus*-wood. It is viewed as an *Urwaldrelikt* by Palm (1959) and Horion (1960), living in just a few, more or less isolated strong-points of primary woodland. Palm (1959) suggests that in the post-glacial warm period the species would have been distributed continuously over the whole of central Europe and up to the modern Baltic island of Götska Sandön. Buckland (1979) provides further details about its biology and distribution, which ranges from southern Sweden, through to Germany and into Central Europe. Westwards it is known from France (Horion, 1960), Portugal (Buckland, 1979) and into Switzerland (Gistl, 1829). Porta (1929) also records in a number of different regions across Italy. Eastwards it has been found in Slovenia (Whitehead 1992b). Figure 12.6 illustrates its known distribution.

12.4.8 Bothrideres contractus

This species was recovered from Blackwater Dike, Thorne Moors, dated to between 3444-2445 BC (dendrochronological date). Girling (1985) also recovered this species from Stileway, Somerset (> 4470 ± 70 BP, 3360-2920 cal BC). This colydiid has also been found in interglacial deposits in the Humberhead Levels, at Austerfield (Gaunt *et al.*, 1972). Dajoz (1977) regards this species as a Tertiary relic under threat of extinction and it is considered an *Urwaldrelikt* (Vogt, 1967b). The larvae of this species feed on other larvae of different xylophagous taxa of Anobiidae, Buprestidae, Bostrychidae and Cerambycidae (Dajoz, 1977). The larvae live with the imago in the wood of *Salix*, *Populus* (Reitter, 1911), *Fagus*, *Quercus*, and more rarely in *Pinus*.

This very rare species occurs sporadically in large parts of south and central-east Europe as far east as Siberia, including Romania, France, Greece, south Finland, Sweden and Norway (Dajoz, 1977). It is also found on the Baltic islands of Öland and Göthland, Lithuania, Poland, Czechoslovakia, Yugoslavia (north of Serbia), Greece, Italy (Piedmont), Switzerland, Germany and Austria (Dajoz, 1977). Figure 12.7 shows its distribution.

12.4.9 Mycetina cruciata

This species has been found only from Thorne Moors. It was recovered from the Blackwater Dike succession, dated to between 3444-2445 BC (dendrochronological date). It was also recovered from the trackway site indicating that it found favourable habitats on the Moors at least until 1390-1060 cal BC (2980 ± 110 BP, BIRM-337). Buckland (1979) discusses the biology of this species in detail (1979). This very rare *Urwaldrelikt* prefers very moist wood in a very advanced state of rot. It is found in all types of wood but appears to prefer conifers (Palm, 1951), in *Polyporus* spp. (Horion, 1961). Lundberg (1984) recovered it in fire-damaged woodland.

The distribution of this species includes Germany (Reitter 1911). Horion (1962) indicates central and southern Europe in mountainous areas only, Caucasus, Russia, into Karelia, the Baltic and southern Finland, south and central Sweden, Norway (Oslo area), Denmark, Poland (Carpathians), Czechoslovakia, Bulgaria, Italy, (the southern slopes of the Alps, Julian Alps, Piedmont, in the mountains of Latium and Calabria, the Italian islands), Spain (Pyrenees), France (Vosges, Alps, Massif Central, Pyrenees), Switzerland, Austria where it is rare. Figure 12.8 shows this broad distribution; it is emphasised that it is not continuously found in the areas marked and is usually restricted to mountainous region, perhaps indicating its requirement for undisturbed habitat. It is interesting that at Thorne Moors it is found in a lowland context, suggesting that its choice of habitat is likely to be limited by surviving habitat, rather than a preference for mountainous regions.

12.4.10 Stagetus borealis (formerly Theca pellita or pilula)

This species was originally recovered from deposits on Thorne Moors by the author (Whitehouse, 1993), but was not identified and was recorded as "Species A", on the basis that it did not match any known British species. The fossil was sent to entomologists in Finland and was subsequently identified by Petri Martikainen of Joensuu University, Finland, who is a specialist in ancient woodland Coleoptera. The fossil dates to sometime after 4515 ± 70 BP (CAR-232), 3350-3100 cal BC and is the only fossil record for this species.

This anobiid is associated with primeval woodland, where it lives on the fungus *Fomes pinicola* and in dead wood with mycelia of fungi (Koch, 1989). Palm (1951, 1959) found this very rare species in Sweden in *Betula* wood as well as under the loose bark of rotting *Quercus*. In Finland, Norway and Sweden, it is regarded as a rare species and is often associated with *Polyporus* species on conifers (Martikainen, *pers. comm.*, 1997). In addition to the Fennoscandian records, Palm (1959) records having taken this species on Rhodes, where it was recovered in large numbers in tree fungi on *Cedrus* and *Planatus*. The preferred habitat of this species thus seems to be in tree fungi in primary woodland, although Lundberg (1984), Wikars (1992) and Ahlund and Lindhe (1992) regard it as a fire species, occurring in 5 to 25 year-old successions after fire. Martikainen (*pers. comm*, 1997) also took this species from a recently burned tree in Russian Karelia.

Apart from the above records, the species is not known from Denmark, Estonia, Latvia and Lithuania (Silfverberg, 1992), although Koch (1989) records it from Central Europe, mainly in Germany (Koch, 1989). Porta (1929) records it from Corsica and Lazio, Italy. An 1880 publication by Rupertsberger records it "in Europe", which might suggest that it was formerly more widespread. However, the majority of the old entomological literature does not appear to list this species, which suggests that it is very rare. In addition, there have been a number of nomenclatural changes to this beetle, which may have added to confusion. Figure 12.9 shows the current distribution of this species, which appears to exhibit a rather continental distribution, although availability of habitat is likely to be key to its distribution.

12.4.11 Members of the genus Rhyncolus

Three non-British members of the saproxylic weevil genus *Rhyncolus* (= *Eremotes*) were also recovered: *R. elongatus* and *R. punctulatus, sculpturatus*. All these species have been recovered previously as fossils on Thorne Moors (Roper, 1993; Whitehouse, 1997a, b). Their presence in deposits from Hatfield between > 3350-3030 cal BC (4480 ± 45 BP, SRR-6119) and 2445 BC (dendrochronological date) and Rossington *c.* 1520-1310 cal BC (3145 ± 45 BP, SRR-6134) indicates their former widespread distribution, at least across the Humberhead Levels, where they sometimes occurred abundantly. Members of this genus live in moist rotten wood of both standing and fallen trees (Palm, 1959). They invade wood at a rather late decaying stage and live in the wood for several generations (Sippola, *pers. comm.*, 1997).

R. elongatus inhabits rotting pinewood (Palm, 1953; 1959) in scattered localities throughout Europe and North Africa, including southern Fennoscandia, France, Germany, Italy and Algeria (Reitter, 1916; Porta, 1932; Hoffman, 1958; Palm, 1953). It is also found in Finland, Karelia, Sweden, Norway, Estonia, Latvia, Lithuania (Silfverberg, 1992) (Figure 12.10). As a Holocene fossil, it has previously been recorded from Church Stretton, Shropshire (Osborne, 1972). At Thorne Moors it occurred at Blackwater Dike in samples dating to > 3444-2445 BC (dendrochronological date); > 2920-2660 cal BC (4230 ± 70 BP, CAR-309), on the east side of the Moors (Roper, 1993) and > 3350-3100 cal BC (4515 ± 70 BP, CAR-232) on Snaith and Cowick Moors (Whitehouse, 1993). On Hatfield Moors, it was recovered abundantly from the Tyrham *Pinus* woodland (2921-2445 BC) and from HAT 3 (> 3350-3030 cal BC) (4480 ± 45 BP, SRR-6119).

Its rarer congener, *R. sculpturatus*, (=*R. nitidipennis* Thoms.) is found in both rotting coniferous and deciduous trees, including that of *Pinus*, *Abies*, *Betula*, *Alnus* and *Fagus*

(Palm 1953; 1959). It is found across areas of central Europe (Reitter, 1911), including southern France (Gaubil, 1849), and the northern part of Italy (Bargagli, 1883; Porta, 1929). It is rare across all Fennoscandia and the Baltic States (Silfverberg, 1992) (Finland, Karelia, Sweden, Norway, Estonia, Latvia) (see Figure 12.11 for its distribution). Its recovery at Thorne dates its presence to >3350-3100 cal BC (4515 ± 70 BP, CAR-232) (Whitehouse, 1993) and > 3444-2445 BC (dendrochronological date) at Blackwater Dike. On Hatfield Moors, it occurs at HAT 3 at > 3350-3030 cal BC (4480 ± 45 BP, SRR-6119), and in the Tyrham *Pinus* woodland from 2921-2445 BC. Lekander *et al.* (1975) also found this species as a fossil in Piilonsuo bog, southern Finland, dated to 2900-1700 cal BC (3850 ± 200 BP) (see Figure 12.11 for the location of this site).

R. punctulatus, is known from central Europe where it feeds on deciduous as well a decaying coniferous stumps (Palm, 1959; Reitter 1916). In Fennoscandia, *R. punctulatus* has been found only in Sweden, from the island of Göska Sändon (Palm, 1959), but it is not found in Finland (Silfveberg, 1992), suggesting that this may be thermophilous (Figure 12.12). Fossil occurrences are from Neolithic/Bronze age deposits at Stileway, in the Somerset Levels (Girling 1985). It has also been found from Thorne Moors (>3350-3100 cal BC, 4515 ± 70 BP, CAR-232 [Whitehouse, 1993]), Hatfield Moors (*Pinus* woodland at Tyrham, 2921-2445 BC) and from Rossington, dated to 1520-1310 cal BC (3145 ± 45 BP, SRR-6134), which represents the latest date for this species.

All European members of the genus, with the exception of *R. reflexus* Boh, have now been recovered from British fossil deposits, including *R. strangulatus* Perr., another species of rotting *Pinus* wood (Osborne, 1972). The fact that four species of the same genus have disappeared from the British Isles within the last 3000-4000 years may be attributed to the demise of its preferred host, *Pinus sylvestris*.

The sole present day British member of the genus, *R. ater* L. (= *Eremotes ater* L.), has also been recovered from the Humberhead Levels. This species clearly used to be more widespread and is one of the commonest pine-loving species to be found as a fossil, yet today most of its records come from the Scottish Highlands (Alexander, 1994). As a fossil, its occurrence ranges from, Somerset (Girling, 1980), Hertfordshire (1989), Norfolk (Kenward and Allison, 1994), Staffordshire (Osborne, 1980), Shropshire (Osborne, 1972) as well as south and north Yorkshire (Buckland, 1979; Roper, 1996; Whitehouse, 1997a, Chapters 6 and 8; Hall and Kenward, 1990). Carr (1916) collected it in Sherwood Forest suggesting that it had survived in England into this century, although it may have become largely restricted to the native Scottish *Pinus*-woods. It has recently been recovered from Irish mire deposits, from a *Quercus* bole, although it is not on the current Irish list (Reilly, *pers. comm.*, 1997). Zetterstedt (1828) includes the species in his *Fauna Lapponica,* but excludes the other members of the genus. This suggests that either the other species had yet to be recorded or that *R. ater* is rather more cold-tolerant than other members of the genus.

Closely associated with the genus *Rhyncolus* is the curculionid *Dryophthorus corticalis*, which was added in 1925 to the British invertebrate list by Donisthorpe (1939), who discovered it in Windsor Forest in damp, tough wood inside old *Quercus,* infested with the ant *Lasius brunneus*. It is an endangered species in Britain, its present limited range determined by the lack of suitable habitats. As a fossil, the species has been found frequently associated with the genus *Rhyncolus*, and its close association has been demonstrated by the CA analysis described in Chapter 9.

In Britain, this species is associated with *Quercus*. Within fossil contexts at Hatfield, the beetle was clearly living in *Pinus* (e.g. sample 1, Tyrham Hall Quarry). This was also the case in southern Finland, at Piilonsuo bog (Lekander *et al.*, 1975). Palm (1959) describes it as attacking both *Quercus* and *Pinus*, where the wood is still hard and firm; Koponen and Nuorteva (1973) found its fossil associated with *Pinus*. It is possible that with the decline in *Pinus* habitats in Britain that the species was constrained to live in *Quercus*. If that is the case, why is it not associated with the Caledonian *Pinus* forest? In addition, why is its close associate, *Rhyncolus ater* able to live in these northern forests, but not *Dryophthorus corticalis*? This "splitting" of former close associates would merit closer attention, and suggests that whilst *R. ater* was able to inhabit the northern forests, its associate was not. This could be interpreted in terms of thermal requirements by *Drophthorus corticalis*. Many insects become most host specific at the limits of their range (Allen, 1956). If *Quercus* is its preferred host, then its presence on *Pinus* as a fossil could be taken to indicate that it had not reached its thermal limits and that it has contracted due to climate change.

12.5 The importance of the extirpated and rare species

Most of the above species would be termed *Urwaldrelikt* species, and are today extremely rare across Europe. The fossil record indicates that these species' former distribution included Britain, and that this country was once much richer in *Urwaldtiere*. Osborne (1965) was the first to point out the Old Forest (*Urwaldtiere*) element in many early to mid-Holocene fossil beetle assemblages, and the fossils from the Humberhead Levels provide the best British examples of such assemblages. The demise of many of the species recovered from Holocene deposits has been attributed to the destruction of undisturbed forest habitats and in particular to the disappearance and lack of continuity of dead wood habitats (Buckland 1979). There may also have been the subtle interplay of climate change (Whitehouse *et al.*, 1997). Many saproxylic invertebrates have typically long periods of development, sometimes several years, hidden within decaying timber as larvae or pupae. They often inhabit only a proportion of potentially suitable trees, which in turn represents a small proportion of the total tree population of most forests. Many often have short imaginal life spans (McLean and Speight, 1993). The recovery of these species in these deposits is therefore highly significant.

The few studies which have examined natural successions indicates that it is still too early to really quantify the number of extirpations, although to date 38 pre-Linnean "extinctions" have been recorded amongst British Holocene Coleoptera (Table 12.2). Twenty-five of the records represent saproxylic species (65%), with the rest coming from beetles representing a variety of threatened habitats, including those associated with wetlands and meadowland. Each study of suitable deposits adds more to the list. The limited number of studies of suitable deposits, as well as problems associated with the identification of species which cannot be identified on characters recoverable from the fossil record (i.e. cannot be identified based upon their head, thoraces or elytra), suggest that these fossils represent a tiny proportion of the range of species which formerly lived in Britain. Almost half these records have come from the Humberhead Levels, particularly Thorne and Hatfield Moors, although sites in the Somerset Levels, such as Stileway (Girling, 1985), have provided a good range of species. The paucity of comparative studies makes it difficult to assess whether Thorne and Hatfield Moors are unique examples of an increasingly fragmented *Urwald* forest within the British landscape, or whether they just represent a good example of what formerly existed.

Although Britain has lost many faunal species associated with these ancient woodlands, there is still a relic *Urwald* fauna in scattered enclaves (e.g. Harding, 1978). Many of those species live today in ancient forests such as Sherwood Forest, Windsor Forest and the Caledonian pinewoods. The fossil record indicates that the distribution of many species was formerly much more widespread. For instance, the RDB 3 colydiid *Colydium elongatum* is largely restricted to the New Forest, Windsor and scattered localities in Dorset, Wiltshire and Surrey (Hyman, 1992). Its presence as a fossil at Thorne Moors and Rossington and at Caldicot, Gwent, in Bronze age deposits (Osborne, 1997b) suggests that this species lived across a wider area.

Saproxylics have declined not only in Britain, but also across Europe (Speight, 1989; McLean and Speight, 1993), although the survival into the post-medieval period of large tracks of virtually untouched forest in some remoter areas of central Europe have provided important refugia for many of these species (Peterken, 1996). More recently, however, large numbers of these species have declined in the boreal forests of Fennoscandia (Heliövaara and Väisänen, 1984; Kaila *et al.*, 1997), following increased felling and grazing in the latter part of this century (Peterken, 1996). Most of the contractions in populations are associated with the later stages of wood decomposition, and whilst the biology of many of these species is qualitatively well-known, quantitative information concerning the micro- and macro-habitat requirements of individual species is still scarce (Kaila *et al.*, 1997).

12.6 When did species become extinct?

On the available data, it is difficult to know when many species became extinct. Superficially, many of the last fossil dates (Table 12.1) for many of these species indicates that they were still present within the British landscape sometime between *c.* 3000 cal BC and 1000 cal BC, after which many seem to disappear from the fossil record. However, this probably reflects the larger number of natural deposits studied from this period compared with subsequent periods; this is compounded by the difficulty of finding suitable deposits covering the last 2000 years.

Some of these species may have persisted in certain areas until relatively recently. Such an example is the cerambycid *Cerambyx cerdo* which is not on the current British list. Several fossil records of this species indicate that it was present in Britain about 4000 years ago (Duffy, 1968; Harding and Plant, 1978). Duffy (1968) reviewed the records for this species and noted that it was recorded by several Coleopterists in the earlier part of the 19th century, suggesting that it may have managed to survive in some areas until then. Alternatively, it may have been re-introduced at about this time, although the decline in records during the 19th century would suggest that its population was contracting rather than expanding. To the author's knowledge, no thorough review of old collections has been carried out to investigate whether other early British records of some of the extirpated species exist. Many old species records were dismissed by later Coleopterists, being regarded as "European" rather than British records and were thus never included within the British lists (Osborne, 1997a). Such work would include not only laborious checking of old catalogues but also of old collections. Even within major institutions, cataloguing of insect collections is still being undertaken and there must be smaller, lesser known-collections within the ownership of small institutions and private individuals which would merit specialist attention.

Much less consideration has been directed to the issue of the European origins of the British entomofauna and the mechanisms of insect dispersal at the end of the Devensian. It may be assumed that many of the our faunal elements originate from the central European forests, moving northwards with increasing temperatures. However, looking at the distribution maps of some of the extirpated species it would appear that two biogeographical elements are represented within these faunas: those whose current distribution is south of the 17° C July isotherm and which display distinctly southern distribution and those which appear to have a greater affinity with Fennoscandian faunas. This element is evident not only in the distribution of these species, but also in the particular suite of species, mainly those associated with *Pinus sylvestris*, which appear to have a significant boreal component. It is worth noting that one of the closest comparable fossil insect records to the Thorne and Hatfield faunas comes not from within Britain, but from Piilonsuo, a *Pinus*-mire in Finland (Koponen and Nuorteva, 1973). This data might suggest that the origins of many of these saproxylics was from both the central European and Fennoscandian forests. Research by Bennett *et al* (1991) and Willis (1996) suggests that many of the trees upon which these populations ultimately depend originated from refugial areas in southern Europe. Each refugial area may have been an isolated community which led to genetic variation amongst some trees as well as animals, creating different genetic lineages (Willis, 1996).

The author noted several morphological differences between the fossil specimens of non-British *Rhyncolus* species examined and the comparative modern specimens, all of which had come from central Europe. The morphological differences concerned the shape of the eyes, which were distinctly flatter compared with the modern specimens. Since all relevant body parts were recovered amongst the fossil assemblages, in some cases still intact to the abdomen, it was clear this was not a case of mis-matching different elytra with the wrong set of heads and revealed a clear morphological difference between the modern material and the Thorne and Hatfield specimens. It is possible that these differences in morphology are related to the existence of two or more genetic populations of this genus/species, brought about by genetic isolation in different glacial refugia. Comparative work between modern and fossil material DNA could elucidate differences of populations and their possible pathways of dispersal, together with their hosts, from glacial refugia. It may also be possible to identify some of the pathways and mechanisms with which these insects expanded into the British Isles.

It is much harder to define why these species become extinct. A consideration of the role of climate change is made in section 12.11. However, the biology of many of these saproxylics is considered in detail below, together with some other factors which may have affected these species' biogeography.

12.7 The ecology of saproxylic insects

Many saproxylic species live in primeval forests, where they feed on decaying wood or on the fungi responsible for its decomposition and some species feed and breed only in large fallen trunks (Väisanen *et al.*, 1993). Two characteristics of old-growth forests are important for many specialist species: coarse woody debris and large, mature trees. There has been a resurgence of interest in these saproxylics in recent years, particularly in Fennoscandia, where there has been concern about the status of many of these saproxylics due to forest clearance and the loss of natural disturbance regimes (e.g. Heliövaara and Väisänen, 1984; Biström and Väisänen, 1988; Kaila *et al.*, 1994,1997; Väisanen *et al.*, 1993; Siitonen and Martikainen, 1994; Haila *et al.*, 1995; Martikainen *et al.*, 1996; Niemelä, 1997).

12.7.1 The importance of dead wood and disturbances

Old growth forests are characterised by large volumes of dead, standing and fallen trees. In some cases, the volume of this wood can be equal to that of live trees (e.g. the great forest of Kubany Wald, Schattawa, Poland [Elton, 1966]). These forests are subject to a range of natural disturbances, such as forest fires, storm damages, and floods created by beavers, creating open, sun-exposed places with a considerable amount of dying and dead wood. Such patches emerge locally quite frequently and regionally may always be present, with moderately small inter-patch distances (Kaila *et al.*, 1997). Such small-scale disturbances are part of the natural system within forests, and a highly diverse faunal community is maintained because of such moderate disturbances. The role of natural disturbances is often highly important within such forests, a factor which has all too often been ignored by many palaeoecologists.

The abundance and availability of dead woody debris is a key component of the primeval forest, supporting many of the extirpated and rare species such as those recovered from the Humberhead Levels. This wood-decomposing system has an exceptionally high species diversity (Biström and Väisänen, 1988). Harding and Rose (1986) have pointed out that if dead wood is removed from the forest ecosystem, the system is impoverished of a fifth or more of its invertebrate fauna.

Many of the species recovered from the Humberhead Levels are associated with very mature trees, so the extirpations and contractions in species indicate that not only dead wood was being removed from the woodlands, but that trees were not allowed to reach full maturity (*cf.* Szujecki, 1987). For instance, Szujecki (1987) notes that the number of trees damaged by insects in 150 year-old *Quercus* forest stands is a third of that recorded from 220-350 year old ones, with the lowest number of xylophages recorded on living trees between 120-150 years old (15.5%). Väisänen *et al.*, (1993) also noted that larger trunks had more beetle species.

12.7.2 The importance of microhabitats

Besides the quality of the decaying trunks, various environmental factors appear to affect the occurrence of both common and rare saproxylic species, creating "micro-ecosystems" (Kaila *et al.*, 1997). Many saproxylics have a requirement for widely differing habitats. Kaila *et al.*, (1994) demonstrate strong associations between the presence of saproxylic beetles in unharvested forests in Finland and the infection of *Betula* by specific species of polypore fungi. They concluded that the *Polyporus* species decaying the wood are important for individual saproxylic beetle species, and that there are different specialised beetle assemblages associated with trunks decayed by different *Polyporus* (Kaila *et al.*, 1994). For instance, *Zimioma grossum*, one of the extirpated species recovered from Thorne Moors (Buckland, 1979), is one of these species which appears to be tied to a particular fungus (Juha Siitonen, *pers. comm*, 1998).

The availability of decaying wood in sun-exposed positions appears to be critical to many species (Kaila *et al.*, 1997) and may explain the importance of forest fires in creating such habitat. The decaying forest on the mires of Thorne and Hatfield Moors would have created an abundance of such exposed wood. On Hatfield Moors, the *Pinus* woodland appears to have been rather open in structure and sun-exposed areas with rotting wood would have plentiful.

Lichen species appear to be essential to certain faunal elements (Spence *et al.*, 1997); it is perhaps difficult to recognise that lichens would have been an important component of many British forests, as they still are in the Caledonian *Pinus* and *Betula* forests and in areas of lower pollution. The removal of lichen affects the whole ecosystem through the removal of an important element from the food chain and loss of insulation on the forest floor.

Early successional habitats such as those found in small open areas of forests are also important. For instance, many saproxylics require nectar sources near breeding habitat, which would have occurred in glades and on woodland edges (Harding and Rose, 1986).

12.7.3 Forest history and management

Forest history may be decisive in the survival of many of these invertebrates. Vaisanen *et al* (1993) suggest that if the forest has lost its primeval character due to human activities, then the fauna may be irretrievably lost during this period of forest change. In many cases, species are not able to re-colonise the forests. *"Although old-growth specialists may occur in low numbers in the managed forest, perhaps maintained by immigrants from the old-growth sources, these sink populations probably disappear if cut-overs become too large, hampering movement of individuals between the preferred old-growth fragments"* (Niemelä, 1997, 607). Thus, temporal continuity of habitat may be a significant component in the development and maintenance of many of these saproxylic communities (Spence *et al.*, 1997). The fossil insect from the Moors would support this suggestion.

Fennoscandian researchers have attempted to quantify the effect of clearance and management of forests on saproxylics and suggest that of the *c.* 1,200 threatened species in Sweden, over half are sensitive to both thinning and clear-cutting of the forest (Niemelä, 1997). Studies in Finland (Kaila *et al.*, 1997; Väisänen *et al.*, 1993) suggest that whilst there may be little difference in species richness between old growth and managed forests, the number of rare species is much higher in old-growth forest than in managed forest (Niemelä, 1997), and furthermore that the specialist species of old-growth forest do not survive in the managed forests (Biström and Väisänen, 1988, 44). Indeed, amongst the abundant saproxylic species, there appear to be few species in common between managed and unmanaged forests (Väisänen *et al.*, 1993) and that managed forests are unable to maintain the original fauna of primeval forests. They conclude that *"The real primeval species seem to be prisoners of the existing remnants of primeval forests"* (Väisänen *et al.*, 1993, 107), and that these species are likely to disappear, especially in small forest fragments.

12.7.4 Effects of clearance on saproxylics

In an ancient forest, organic matter and nutrients accumulate in the standing crop of trees and shrubs and in the organic debris of the forest floor. All this debris acts as an insulating layer (Biström and Väisänen, 1988), and clearance has the effect of creating exposed habitat, with increased temperature and moisture and decreased shade (Atlegrim and Sjöberg, 1995). Several species apparently cannot live in the dry, open conditions of managed forests, and require the presence of stable air humidity, protection from sunlight, wind and particularly drought. Such factors are also likely to decrease the survival of invertebrate larvae (Atlegrim and Sjöberg, 1995), and will also affect the wood-decomposing processes attributable to fungi, and consequently the food quality of many invertebrates (Vaisanen *et al.,* 1993).

12.7.5 Forest fragmentation

Geographical and structural forest fragmentation can have a diverse range of effects upon forest invertebrates. For instance, instead of a decline, species richness may actually increase in small forest fragments (Niemelä, 1997), although it is unclear how long this lasts for and what the quality of this species "richness" is. Niemelä (1997) however, points out that there is a positive correlation between the richness of true forest dwelling invertebrates and the size of a forest fragment. Geographical isolation usually reduces species richness as some species are poor disperses or restricted to particular habitat types and isolation can cause extinction of a species, or genetic changes and shifts in habitat quality (Dennis, 1997).

12.7.6 Mobility

Saproxylic species are characteristically found in only a proportion of potentially suitable trees, which are often only a small fraction of the total tree population of most forests (McLean and Speight, 1993). The mobility of species is, in general, poorly known, and most probably varies remarkably between species (Kaila *et al.*, 1997). Much of the available evidence supports the view that they have very limited powers of dispersal (Wormell, 1977; Warren and Key, 1991). It is unlikely that in primeval forest conditions, where there was almost continuous forest cover and an abundance of dead wood, that habitat availability was a problem, since suitable hosts may have been present within the distance of a few metres (Warren and Key, 1991). Under such conditions, there was presumably little selection pressure to evolve strong flight/dispersal ability (McLean and Speight, 1993). The poor mobility of many of these species is likely to have had an important element in their decline and extirpation in the British Isles.

However, the fossil insect evidence indicates that this is not the whole story. One has to ask how forest Coleoptera with apparently low dispersal ability appear in the early-mid-Holocene fossil record. Jordan (1995) points out that faunas from Ballyglass, Ireland illustrate that despite their "low powers of dispersal", major components of the "*Urwald*" faunas were able to reach Ireland. The recent recovery of *Rhyncolus ater* and *Prostomis mandibularis* within Irish deposits by Eileen O'Reilly (*pers. comm*) confirms

Jordan's assertions. It seems that as long as *Urwald* forest remained, mobility and dispersal of these saproxylics was not a problem, but once the corridors of forest had fragmented because of widespread deforestation, many species were no longer able to re-colonise and became isolated within small biogeographic islands, such as on the wetlands of the Humberhead and the Somerset Levels. In addition, it appears that not only was the *availability* of corridors important, but also the *quality* of those linking forests, which may not have contained the longevity and structure of *Urwald*. Much of the Fennoscandian literature indicates that once the forest has lost its primeval character, the fauna may be irretrievably lost and species are unable to re-colonise (Biström and Väisänen, 1988, 44; Vaisanen *et al*, 1993).

12.8 The decline of *Pinus sylvestris* and heath

There appears another contributory factor to these insect extinctions. Many species recovered from the Humberhead Levels are pinicolous. The decline of this tree within the British landscape may have had a significant role in their decline and extirpation (*cf.* Whitehouse, 1997b). Despite the broad environmental tolerance range of *Pinus*, which grows on a wide variety of soils, the loss of this habitat to many of its associated invertebrates is reflected in the fossil record from the Humberhead Levels. During the Holocene, *Pinus* had become increasingly restricted to marginal areas, such as developing peat bogs, which it readily invades if surface conditions become suitable (McNally and Doyle, 1984).

Pinus was abundant during the early Holocene, being present widely but locally in southern England 9,000 years ago, spreading northwards between 9,000 and 8,500 years ago (Birks, 1989) and reaching its maximum extent *c.* 5700 years ago (Bennett, 1995). However, by *c.* 3000 cal BC (4400 BP) *Pinus* appears to have undergone a sudden and widespread decline (Bennett, 1984, 1995; Bridge *et al.*, 1990; Gear, 1989; Gear and Huntley, 1991). The most widespread view is that the decline was caused by a shift to cooler and wetter climatic conditions, by promoting the expansion of blanket peat to the detriment of *Pinus sylvestris* (Bennett, 1984; Birks, 1990; Gear and Huntley, 1991). Trees growing in marginal locations may have been particularly vulnerable to short-term acidification, pollution or increased soil moisture, particularly if they were already stressed by a longer-term climatic change (Blackford *et al.*, 1992). Bradshaw (1994) suggests that the decline in populations in western Europe during this period may be explained by the decreased occurrence in wildfire, in response to climatic change.

However, the perceived "*Pinus* decline" may be a product of the palynological record and the broad age ranges generated by radiocarbon dating of material from this date. The dendrochronological evidence suggests that *Pinus* declined in a protracted fashion, rather differently to the sudden *Pinus* decline noted in the palynological record (Lageard *et al.,* 1995). Boswijk (1998) noted that her *Pinus* chronologies indicated the presence of this tree on the mire at Thorne Moors long after Smith's (1985) *Pinus* decline. Pollen productivity from *Pinus sylvestris* is likely to have been severely reduced, as it is often stunted and flowers poorly in such environments (Bennett, 1995).

The fossil insect record suggests that *Pinus* continued to be an important component of the British landscape, after the decline. Today there is a continued reduction in the total area occupied by native *Pinus* forest, apart from the Caledonian forests, which are reduced to small fragments (Gimingham, 1977), and a substantial reduction in its associated invertebrates. There is a close affinity between pinewoods and lowland heath communities, and heaths would have provided an important habitat for *Pinus.* Cartographic evidence from the Humberhead Levels indicates that there were extensive areas of heath, besides raised mire, both of which formed an important refuge for *Pinus* and its associated taxa. The fossil insect from Hatfield Moors and Rossington indicate that heath was an important ecological component within this landscape from about 4000 years ago. Once widespread, heath is today one of the most threatened habitats in Britain (Gimingham, 1977). Evidence from Cowick (Girling in Hayfield and Greig, 1989) suggests that a relict *Pinus*-heath and pasture-woodland fauna survived into the medieval period. At Wood Hall, during the early part of the occupation of the site Wagner and Pelling (1995) found evidence for areas of heath. However, this component had disappeared by the time the next context was deposited.

Hunter (1977, 44) points out that at least five of the specialist Caledonian *Pinus sylvestris* relic species today occur in east Norfolk (an area which supports extensive heath), which is also the main centre in the UK for the largely pinicolous longhorn beetle *Leptura rubra* (L.). This group of species may represent a relic *Pinus* fauna, which has survived in an area where there may have been sufficient continuity and abundance of *Pinus,* although there are now no relict pinewoods (Hunter, 1977). Speight (1985) highlights the faunal effects of the disappearance of *Pinus* from the Irish landscape, where only a residuum of saproxylics characteristic of this habitat are found on the present Irish invertebrate list. New fossil insect work on Irish material is beginning to highlight the loss of pinicolous elements from Ireland (e.g. *Rhyncolus ater*, O'Reilly, *pers. comm.*).

Many of the extirpated species recovered as fossils from the Humberhead Levels are pinicolous, such as the ostomid, *Temnochila coerulea* Ol., (Frontpiece) (Whitehouse, 1997a,b), from deposits dated to > 3350-3100 cal BC (4515 ± 70 BP, CAR-232). It is described in the European literature as a rare *Urwaldrelikt* (Reitter 1911). Its distribution and biology have been published in detail previously (Whitehouse, 1997a, b) (Figure 12.13) The disjunct record of this forest species in central and southern Europe, western Asia, and north Africa suggest that forest clearance and the loss of *Pinus sylvestris* habitats are responsible for its disappearance over a large part of its range, although changes in climatic factors cannot be excluded (Whitehouse *et al.*, 1997). The fact that four species of the *Pinus*-loving genus *Rhyncolus* have disappeared from the British Isles within the last 3000-4000 years suggests that their demise may match that of its preferred host, *Pinus sylvestris.*

Table 12.2 displays the extirpated taxa from the Humberhead Levels. Out of the listed twenty species, nine are pinicolous. These include *Buprestis rustica, Cryptolestes corticinus, Stegetus borealis,* discussed in detail above, as well as the weevil *Pissodes gyllenhali,* which was recovered on the eastern side on Thorne Moors by the author (Whitehouse, 1993, 1997a). This curculionid is common in Fennoscandia, living on the phloem of freshly-fallen *Picea* and *Pinus* in shady coniferous forests species (Juha Siitonen, *pers. comm.*, 1997). It is found all over Fennoscandia and the Baltic countries (Silfverberg, 1992) and appears to have a distinctly eastern distribution (Figure 12.14)

The fossil record also indicates that other *Pinus sylvestris* taxa were formerly more widespread, today restricted to habitats associated with the native pinewoods of Scotland. *Rhagonycha elongata* (Fall.) is characteristic of northern pinewoods (Hyman 1992), but was recovered from mid-Holocene deposits in Somerset (Girling 1977a; 1978), along with *Mycetophagus fulvicollis* F. (Girling, 1977), a species whose latest records are from Scotland. *Corticeus fraxini* (Kug.) is thought to have been introduced in 1922 (Allen, 1963; Hammond, 1974); however, the recovery of this species from the trackway at Thorne Moors (Buckland 1979) attests its native status. The RDB 1 ostomid *Ostoma ferrugineum* was very common in the deposits from Hatfield Moors and Rossington. Today, this species is extremely rare and is largely confined to the Scottish pinewoods (Hyman, 1992). The scolytids *Tomicus minor, Pityophthorus lichtensteini* and *Pityogenes quadrigens* are regarded as native only in Scotland, and all have an RDB rare status (Hyman 1992). The fossil record indicates that all these species had a far more widespread distribution in the past. All species were common within the deposits studied and have been found previously from Church and Little Stretton, Shropshire (Osborne 1972), and the Trent Valley (Dinnin, 1997e).

12.9 The importance of fire habitats

Some insect species associated with *Pinus* are, to some extent, also fire-dependent (Hunter, 1977). Fire represents a natural factor in the boreal forest ecosystem and helps to maintain the diversity and long-term stability of the forest (Biström and Väisänen, 1988, 5). Buckland and Dinnin (1993) first pointed out that the disappearance of fire habitats may have contributed to the demise of particular elements of the British fauna.

Forest fires increase insect diversity in a number of different ways. Firstly, they create habitat for the development of strictly pyrophilous species; secondly, they kill trees, which allows species which are dependant upon dense piles of sun-exposed wood to develop. Fire-killed wood dries out quickly and has a unique pattern of decomposition. Fire also alters the age-structure and tree-species composition of an area (Wikars, 1992). Under the dynamics of a natural fire regime, deciduous trees like *Betula* are much more common (Wikars, 1992), creating a mosaic of different forest successions, with earlier stages being dominated by deciduous trees such as *Populus tremula* and *Betula* species. In the absence of further burning, *Picea* and *Pinus* eventually invade and *Populus tremula* and *Betula* die out (Wikars, 1992). The suppression of fire regimes within the Scottish Caledonian *Pinus* woods may, at least partially, explain why *Betula* has become a far less important component within these forests.

Fire can affect insect populations in a radical way (Harris and Whitcomb, 1974; Fowles, 1988), although few studies have attempted to quantify its the impact on insect faunas, with a few notable exceptions in Fennoscandia (*cf.* Lundberg, 1984; Ahlund and Linde, 1992; Wikars, 1992; Muona and Rutanen, 1994; Midtgaard, 1996). Muona and Rutanen (1994) ignited a series of forest fires in Finland to study the response of insects to fire. Their results indicate that fire specialists are not only saproxylics, but come from a range of ecological groups and form a specialist community.

Phyrophilous species appear to develop almost exclusively in burned areas, usually only one to five years after a burn. Wikars (1992) puts forward three hypotheses to explain why these species are attracted to fires. In the first instance, fire removes a substantial part of the present fauna and creates new substrates (such as burnt ground and trees) for pyrophilous species to colonise. Species which arrive in the burnt areas quickly are able to gain advantage over other species, as a consequence of successively increasing interspecific competition. Secondly, a newly burnt area is a unique habitat in several respects. The fire blackened tree trunks and ground have much higher temperatures than surrounding areas. Certain fungi develop almost exclusively on burnt trees, attracting particular types of insects. Finally, it is believed that pyrophilous species are tied to fires as a means of mate-finding; for instance, females of *Melanophila acuminata* (Deg.) lay eggs under the bark of fire-killed trees where the larvae develop.

During the fires flames can reach about 900° C. However, the heat usually reaches only a few centimetres into the soil, so that a substantial part of the soil-dwelling fauna as well as seeds and roots survive. Small spot fires can occur in ants nests, continuing to burn for days and act as activity centres for pyrophilous insects (Wikars, 1992).

A range of pyrophilous species are associated with the burnt woodland on Thorne and Hatfield Moors. Species such as *Dromius quadrinotatus* Zenk, described by Palm (1959) as a "fire species" and *Corticaria linearis* (Payk.) seem to especially prefer mould fungus under dead bark of trees damaged by fire (Palm, 1959), primarily in coniferous woodland (Hyman, 1994). Both were recovered from burnt *Pinus*-wood on Thorne Moors by the author (Whitehouse, 1993). Flight holes of *Arhopalus rusticus* (L.) were observed amongst the *Pinus* wood piles at Thorne Moors (Whitehouse *et al.*, 1997), and are typically found in *Pinus* stumps, particularly in burnt areas (Kaufmann, 1948). According to the entomological literature, this species appears to be native only in Scotland, although it has spread with plantations to England (Alexander, 1994); the fossil occurrence of this species indicates its former occurrence in south Yorkshire, at least from *c.* 2921-1489 BC (*Pinus* woodland chronology), until the medieval period, when it became incorporated into deposits at Cowick (Girling, in Hayfield and Greig 1989). Elsewhere, Dinnin (1996) recovered *Salpingus ater* Illiger associated with trees damaged by fire at South Lochboisdale, S.Uist, Outer Hebrides. This species is often associated with burnt twigs of deciduous and coniferous trees (Hunter, 1977; Palm, 1959); today this beetle is found in areas of woodland growing on heathland which is susceptible to fire (Dinnin, 1996).

Several of the extirpated fossil Coleoptera are associated with fire. The non-British ostomid *Zimioma grossum* (L.) was found as a fossil on Thorne Moors, dated to 1390-1060 cal BC (2980 ± 10 B.P, BIRM-337) (Buckland, 1979) as well as from Neolithic deposits dating to 4350-4170 cal BC at Runneymede, Surrey (Robinson, 1991). Its ecology is interesting, as it is described as being associated with *Urwald* and particularly *Betula* damaged by forest fires (Palm 1951), although it is also found on coniferous trees (Horion, 1960). Wikars (1992) recorded it invading fire sites between 5 to 25 years after fire. However, entomologists studying old forest faunas in Finland and Karelia suggest that it lives in large brown-rot snags of different tree species, preferably decayed by the polypore *Fomitopsis pinicola*, (Juha Siitonen, *pers. comm.*, 1997). They suggest that *Z. grossum* does not particularly require fire, but that key to this species' requirement is brown-rot wood, which can be a very scarce resource in intensively managed forests. They suggest that intensive forestry explains its threatened status in Finland (Martikainen, *pers., comm.*, 1997) and that the pyrophilous status of this species remains uncertain.

However, there are other non-British species whose association with fire is recognised. Muona and Rutanen (1994) recorded an increase in *Stagetus borealis* following fire, an association which Lundberg (1984), Wikars (1992), Ahlund and Lindhe (1992) and Martikainen note (*pers. comm*, 1997). The affinity between *Pterostichus angustatus* and fire has been discussed at length (section 12.4.1), and it is likely that decline of this habitat has had a detrimental effect upon its distribution. The cossinine *Rhyncolus elongatus* is known from charred *Pinus* (Fairmaire, 1916), although this is the only reference to its preference for fire-damaged woodland. Roper (1993) recovered a single specimen of *Caenoscelis subdeplanata* from Thorne Moors, a species which is regarded as an introduction in 1954 (Johnson, 1966), until its discovery in fossil deposits. This mould feeder is recorded as associated with fire by Ahlund and Linde (1992). Lundberg (1984) also found *Mycetina cruciata* associated with fire-damaged woodland.

The Notable B bark beetle *Scolytus ratzeburgi*'s, flight holes were commonly noted in the fossil *Betula* on Thorne Moors by Buckland (1979). Subsequently, Roper (1996) recovered this beetle from Thorne Moors and further specimens were recovered from Blackwater Dike (Thorne Moors), in samples containing abundant charcoal (section 8.2.4.2.1). Today this species appears to be confined to the uplands of Scotland, with a preference for mature Betula stands, although in the deposits at Thorne, it has been found in both mature and young *Betula*. Its disappearance from the Lowlands is not easily explained, but it is possible its distribution is affected by the frequency of burns, as it is sometimes found in fire-damaged woodland. If this is one of the species' habitat requirements, it may have restricted its distribution to areas of northern Scotland with its coniferous and *Betula* woodlands, more flammable than other forests.

The suppression of forest fires in Fennoscandia, as elsewhere, together with the removal of dead trees, which could be possible ignition sites during thunderstorms, means that many of these pyrophilous species have become severely restricted (Heliövaara and Väisänen, 1984; Muona and Rutanen, 1994; Midtgaard, 1996), or have disappeared altogether. Wikars, (1992) suggests that the fire-adapted *Agonum bogemanni (Gyll.)* has probably become extinct in north-western Europe. Ahlund and Linde (1992) found twenty-six Red-Listed insect species in recently burned stands of which fourteen were restricted to this habitat. Muona and Rutanen (1994) point out that the importance of fire to many threatened species is probably true of much of western and central Europe, but that competently compiled lists of threatened species are not available for many areas. This is particularly true for some of the eastern European countries, such as Poland, Czechoslovakia, former Yugoslavia and other Balkan countries, such as Albania (McLean and Speight, 1993).

The decline in fire habitats may thus have had a hither-to unrecognised importance in the extinction and contraction in range of many former and current British insects. This evidence also raises interesting questions regarding the former role of natural fire within British forests, particularly within temperate coniferous woodlands, since the majority of these species are associated with these woodlands. Fires appear to have been an essential component within many of these forests, and their decline in frequency has led to the concurrent contraction in range and in some cases, possibly the extinction, of some of its pyrophilous elements.

This decline in fire frequency is likely to be connected with the dwindling of coniferous forest, the most flammable of British forests; possible changes in climate, which may have led to more humid climate and less thunderstorms; changes in the quantities of dead wood and debris available as a source of ignition and combustion and more recently, effective forest fire suppression policies.

12.10 The impact of wetland destruction

Although none of the extirpated species recovered are associated with wetlands, many other species found as fossils are today severely restricted and chart the decline of wetland habitats. It is probable that the last few hundred years of drainage, river canalisation, dredging, scouring of aquatic plants, removal of bank-side vegetation and chemical pollution has reduced many of these species to relic status (Dinnin, 1997e). The analysis of chironomid assemblages show that the most radical modification of the freshwater ecosystem has taken place during the last 150 years, largely due to the impact of pollution (Sadler and Jones, 1997). The range from insects affected include those associated with raised mire and wet heath, those living on the margins of aquatic and semi-aquatic vegetation, and aquatics living in pools and rivers. The following is a necessarily short account highlighting some of these faunal components.

Insects which live in bogs are those specialists to mires, as well as those living at the natural interface between the raised mire and the surrounding vegetation, such as those associated with fen, poor fen and reed swamp or carr (Key, 1988). Since lowland raised mire habitat is so rare in Britain, its invertebrates have declined to such an extent that many of the peatland specialists are on the Insect Red Data Book list (Shirt, 1987) or the Nature Conservancy Council's Reviews of Scarcer Species (Ball, 1992). It is almost impossible to investigate an undisturbed mire and its associated fauna, due to the lack of suitable sites (Heathwaite, *et al.*, 1993). The study of fossil insect populations from mire deposits provides one of the few opportunities to study such assemblages, over a long temporal scale. Of particular importance to many of these invertebrates is site hydrology. Many species are hygrophilous, being aquatic or inhabiting wet moss or accumulations of wet plant litter during some part of their life cycle (Key, 1991). Several species display much vulnerability over even short periods of hydrological fluctuation (Key, 1988).

The recovery of the Humberhead Peatlands' RDB1 endemics, *Bembidion humerale* and *Curimopsis nigrita* within fossil deposits on Hatfield Moors illustrates that the particular character of these lowland raised mires formed about 4000 years ago. *B. humerale* dates to > 2700-2350 cal BC (3990 ± 60 BP, BETA-91800), whereas the fossil of *C. nigrita* is contemporaneous with the *Pinus* woodland at Tyrham, 2921-2445 BC. The latter has also been found as a fossil on Thorne Moors by previous investigations (Buckland and Johnson, 1983; Whitehouse, 1993). Both species are characteristic of lowland peat bogs. *B. humerale* is typical of the narrow band of wet peat at the margin of pools, particularly where there is a thin covering of algae (Key, 1991). This habitat is often very rare as naturally occurring bare peat is probably one of the rarest microhabitats within the natural raised mire system (Key, 1991). *C. nigrita*, lives at the interface between the ericaceous litter and the wet peat surface (Heaver and Eversham, 1991). Apart from the Moors, their distribution is centred upon the Baltic, with the greatest concentration of records in Germany and Poland (Heaver and Eversham, 1991). There are no other records of *C. nigrita* as a fossil, but there are records for *B. humerale*, indicating its former more widespread distribution. As a fossil, it has been recovered from deposits associated with the Sweet Track (Somerset Levels), dated to *c.* 4040-3820 cal BC (Girling, 1984a), as well as from Late Devensian deposits from Gransmoor (Walker *et al.*, 1993).

The survival of these two species must be related to the relative stability of their respective microhabitats on these two mires over the last few thousand years and their continued survival must be in jeopardy as peat winning and drainage of these wetlands continue. Their disappearance from other locations must be related to the human use of peatlands for peat and turf, which appears to have been utilised at least from the late Iron age (e.g., northern Scotland [Carter, 1998] as well as Roman York [Hall *et al.*, 1980]); Chapter 7) and drainage of wetlands, which commenced in some areas in the Roman period (e.g. Rippon, 1996). There are no other fossil records for *C. nigrita* which might throw light upon its former distribution, although it is possible that it has always been confined to the Humberhead Levels: the uniqueness of these mires today has already been noted (section 1.2), and this may have been the case in the past.

The recovery of *Cymindis vaporariorum*, at Hatfield Moors is rather unusual. This boreal species, normally associated with montane peatland sites (Eversham, 1997b), was surprising in a lowland context, and raises the interesting possibility that this species represents a relic population which flourished in the area at the end of the last glaciation (Eversham, 1997b). Hyman (1992) lists its preferred habitat as peat and heather moorland, especially on sandy soils. However, the occurrence of this species as a fossil in the Somerset Levels (Girling, 1977b), a lowland situation, of roughly the same date, indicates that its former range was more extensive, and that this ground beetle's habitat previously included lowland wetland. It is likely that disturbance and erosion of its habitat has restricted this species to more remote montane areas. The areas of exposed sand dunes existing on Hatfield Moors would have been particularly attractive habitats for this species.

There are a suite of other wetland species which seem to have become more restricted or have contracted their distributions. This is particularly evident amongst the fen- and mire-pool aquatics. Water-level stability is the main factor affecting the community structure within such pools, which is easily damaged by drainage (Foster, 1995). The biology of the RDB 2 dytiscid *Hydroporus scalesianus*, which occurred frequently as a fossil on Thorne and Hatfield Moors, has already been discussed (section 6.3.4.2.4). Modern records suggests that this beetle has suffered a large decline. The same applies to many other acidophilic water beetles of the genera *Hydroporus*, *Agabus* and *Ilybius*.

Although there are a good range of acidophilic rare species, many of the rare species are those which today are found in eutrophic fen situations. These include the RDB 1 species *Graphoderus bilineatus*, which is today restricted to Catfield Fen, Norfolk (Hodge and Jones, 1995), the RDB 2 species *Acilius canaliculatus* and a range of Hydraenidae and Hydrophilidae. The RDB 3 *Limnebius aluta*, is common in deposits from Rossington. Today, this species is not recorded in the area (P. Skidmore, *pers.*

comm.), although it was found as a fossil by Dinnin (1992) in medieval deposits at Shirley Pool. The diverse range of members of the genus *Hydrochus* (*H. ignicollis, H.carinatus*; *H.brevis*), all of which are RDB2/3 species suggests that their fen habitat has declined. The RDB 1 Lesser Silver water beetle, *Hydrochara caraboides* is particularly common in samples from Rossington, and is typical of lowland fens (Shirt, 1987). Today, this species is concentrated in peat areas of Westhay and Shapwick in the Somerset Levels, although there are scattered records north to Askham Bog in the Vale of York (Shirt, 1987). Its fossil records indicates its former wider distribution, and that it was common in lowland floodplain fens (e.g. Bole Ings, Dinnin, 1997e).

The RDB 3 Greater Silver water beetle, *Hydrophilus piceus*, was recovered from Hatfield Moors. This species has a very limited, southern distribution within the British Isles and is no longer found as far north as the Humberhead Levels. Its fossil record, however, would suggest that it was considerably more widespread in the past (*cf.* Dinnin, 1991). Dinnin (1991) has suggested that the Little Ice Age may have been a contributory factor in its decline, reducing its habitat range, while subsequent re-colonisation was prevented by the destruction and fragmentation of suitable habitats. However, nineteenth century records from Derbyshire and Huddersfield (Balfour-Browne, 1958), testify the presence of post-Little Ice Age populations in more northerly latitudes.

Pollution and drainage have taken their toll on the aquatic fauna of the area in recent years and consequently many species are appreciably more rare than formerly or are now absent from the district. Even the previously ubiquitous *Ochthebius minimus* is no longer commonly found. This species is common in the sequences from Hatfield Moors, Rossington and Misterton. It was also very abundant in deposits from Sutton Common, (Roper and Whitehouse, 1997). Large numbers of this species in medieval deposits at Shirley Pool (Dinnin, 1992) indicate that it was common at least until this period.

A diverse range of chrysomelids which feed on marsh plants were recovered from Rossington, which are either rare or absent from the region today. *Donacia bicolora* (RDB 2) and *Donacia aquatica* (RDB 3) were formerly widespread, but have a much more restricted distribution (Hyman, 1992). Many of the other common fossil reed beetles are NA or NB species, which indicates that such water-side habitats, formerly abundant, have declined, presumably because of drainage. There are no present local records of *Donacia marginata* or *Plateumaris braccata* (although the latter can still be taken on the Humber Estuary, to the north [Stainforth, 1940]) and no record of *P. affinis* since 1904 (P. Skidmore, *pers. comm.*, 1994).

The presence of *Trechus rivularis* from Rossington is worthy of further discussion Previously, this species has been considered as living in a few remaining undrained fens. The species is described by Pearsen (1961) as "markedly continental" and absent from much of "Atlantic" Europe. It is recorded as a fenland species in Cambridgeshire and Norfolk (Andersen and Meharg, 1989), with isolated occurrences at Askham Bog, North Yorkshire (Holmes *et al* 1990). However, recent surveys have found it to be widespread all over the British Isles in mountain bogs (Luff, 1998), in Northumberland (Luff and Wardle, 1991) and in upland Wales (Holmes *et al*, 1990, 1993). Jordan (1995) notes that there are three further finds reported from areas over 300 m in Northern Ireland. Holmes *et al* (1990) suggest that the true habitat of *T. rivularis* in the British Isles is *Calluna*-dominated blanket bog over 300m and that the other sites represent a relic population. Its fossil record, however, indicates that its former distribution was widespread and the records from the Humberhead Levels suggest that this species had a much wider lowland distribution. It appears that the current records of *T. rivularis*, in isolated areas of upland bog and lowland fen, are the result of widespread habitat loss.

12.11 Evidence for the impact of climate change

The fossil insect faunas from the Humberhead Levels highlight the history of woodland clearance and drainage of wetlands. However, it is less easy to infer a climatic signal from many of these assemblages. When looking at Holocene climatic change from a palaeoentomological perspective, one of the problems is an overall lack of information about the biology and past distribution of species. A limited dating framework and lack of information of *when* species disappear from the fossil record complicate matters.

Species on the edge of their range are more susceptible to edaphic and anthropogenic, as well as climatic change. Superficially, the distributions of the *Urwaldtiere* beetles could imply a more continental climate, and climatic deterioration may account for their subsequent disappearance from Britain. Examining the distribution maps of the non-British species, several beetles may illustrate thermophilous requirements. This is best illustrated by the maps for *Isorhipis melasoides*, *Tenebrioides fuscus*, *Pycnomerus tenebrans*, *Rhyncolus punctulatus* (Figures 12.2, 12.3, 12.5, 12.12). All four of these species has a distribution which is currently south of the 17° C July isotherm, although the information about the distribution of *T. fuscus* is hampered by confusion in the literature over its nomenclature. The remaining species are not found in Fennoscandia, which could substantiate a thermophilous requirement. The current entomology of Fennoscandia is reasonably well-know, but there have been contractions in this areas' fauna also. Moreover, it is difficult to be absolutely sure whether some of these species have not occurred within Fennoscandia sometime within the last century. As Siitonen and Martikainen (1994) point out, very little is known about the abundance of Finnish rare species in the past since quantitative data and even species lists are limited in availability. They comment that Salaas, (a well-known Finnish entomologist), refers to a trip made in 1828 to south-west Finland, where *"the number of rare and nowadays threatened tree-living species collected within two days is surprising"* (p. 189). It is thus difficult without looking at old records to know how accurate many of the distribution maps actually are and whether they reflect the former distribution of these species. It would be dangerous, therefore, to make too many inferences on basis of negative or absent data.

Temnochila coerulea Westw (Whitehouse, 1993) shows a modern southern-European distribution, and could suggest an affinity towards warmer temperatures, although its occurrence on the island of Göska Sändon, off the eastern coast of Sweden, in old forest, suggest a wider tolerance of temperatures, perhaps a preference for a more continental climatic régime. In Fennoscandia, it is considered a relic of the warmer post-glacial climatic period (Juha Siitonen, *pers. comm.*, 1997). This species was recovered in the same deposit as *Scolytus ratzeburgi,* a scolytid which is today confined to the uplands of Scotland and areas of Fennoscandia. Considered together (Figure 12.13), do the distributions reflect variation in oceanicity versus continentality in climate or reflect the differing histories of woodland and forest in the west and Baltic regions (Whitehouse *et al.*, 1997)?

The behaviour of some of the members of the genus *Rhyncolus* is perhaps more interesting. The failure of these species to survive in the British northern *Pinus* refugia may be the result of the effects of habitat destruction and fragmentation and/or unsuitable climate, with the present British refugia lying beyond their thermal range. Species such as *R. ater*, *R. punctulatus* and *R. sculpturatus* are not wholly restricted to conifers, and they also live in deciduous trees in more southern localities. Some of these taxa (e.g. *R. ater*) have been found associated with deciduous trees (e.g. Tyrham *Quercus* woodland), although today they are found in Scotland only on *Pinus*. The close associate of *Rhyncolus* species, *Dryophthorus corticalis* has made a similar switch in hosts, noted above. This may imply a contemporary climate warmer than today, with subsequent minor climatic changes causing species to become increasingly confined to *Pinus*, or *Quercus* in the case of *Dryophthorus corticalis*. The evidence for climate change is thus somewhat conflicting, and is compounded by a lack of published information on these species. In addition, some of these species may yet be found to have been British residents until recently.

Some fossil insect researchers have suggested that there is evidence for a warmer climate during the Bronze Age (Girling, 1984; Osborne, 1972a; 1988) on the basis of the present distribution of some of these extirpated species. For instance, Osborne (1988) suggests that the decline of the genus *Onthophagus*, which used to be relatively abundant in past insect assemblages, but which has become fairly scarce today, may be related to temperature, since its abundance rises to match that of *Aphodius* further southwards across the continent. However, this interpretation may be rather simplistic. *Onthophagus* was taken more commonly last century, and is abundant in material collected in south Yorkshire presently being catalogued at Sheffield Museum (P. Wagner, *pers. comm*, 1998). The link between this species' past distribution and climate change is still to be convincingly proven. Moreover, the destruction of meadowland and old grassland is likely to have been a controlling factor in this species' contraction in range. More recently, Dinnin (1997e) has argued that the insect evidence suggests the presence of a more continental climate during the mid-Holocene. This is argued on the basis of the presence of thermophilous taxa in some of the mid-Holocene sites studied, including the fossils from the Humberhead Levels. However, previous reservations regarding the perceived distributions of these species are relevant here also.

If there had been a change from a more continental to a more oceanic climate, this would result in less successful over-winter hibernation of some beetles. This may effect saproxylic insects in a number of different ways. Temperature effects the length of larval development in some saproxylics. Persistent cold winds can limit the dispersal of emergent beetles, which may stay and breed on the fallen tree they have over-wintered in and make no further migration (Szujecki, 1989). Mobility of beetles tends to be affected by different temperature conditions, with greater mobility in warmer conditions (Biström and Väisänen, 1988).

However, the loss of niche and micro-habitats through forest clearance would have had similar effects to those described above. Saproxylics in the interior of large logs or cavities in trees are buffered from fluctuations in moisture content and temperature. Buffered micro-climates within forests are key to many species (Kaila *et al.*, 1997). The removal of trees and wood through human activities would have had the effect of subjecting many of these saproxylics to increased temperature fluctuations. This buffered habitat is particularly important at the northern edges of a species' range, where climate may be an important limiting factor to the survival of a population (Warren and

Key, 1991). The removal of the insulation provided by the forest would have had an adverse effect upon a population, without any actual change in the macro-climate itself, Many species may thus have had problems maintaining viable populations.

Recent research from Fennoscandia provides some very convincing evidence that habitat disturbance and destruction are the prime factors in the disappearance of many of these species. This is perhaps best illustrated by comparative studies of areas of unmanaged and managed woodland in Russian and Finnish Karelia (Siitonen and Martikainen, 1994). This research indicates that although adjacent, faunal diversity in the Russian Karelian forests is far greater than amongst the Finnish forests, with a much larger number of *Urwaldtiere* species. Prior to the Second World War the forests formed part of the same, largely unmanaged forest. Information on the status of the invertebrates of these forests at this time is available. Research indicates that many of the *Urwaldtiere* species on the Finnish side have become locally extinct, whereas on the Russian side they continue to flourish, "*An eastern distribution may explain the occurrence of some rare species in Russian Karelia that are missing in Finland. However, all the species have earlier been reported from southern Finland*" (Siitonen and Martikainen, 1994, 189). The high number of rare species on the Russian side is attributable to different forest management and particularly the abundance and continuity of large, dead wood. Their study also indicates the scale of human impact on a fauna in only 50 years. In addition, little migration of the rare species appears to have occurred from the Russian to the Finnish side, although the forests are adjacent, suggesting that these *Urwaldtiere* are not able to move beyond their patches of ideal habitat. The saproxylics appear to become further isolated and confined to small biogeographic islands.

Grazing pressures are likely to have adversely affected some of these Finnish forests, where there has been a shift in grazing regime away from domestic animals in favour of moose and roe deer (Bradshaw *et al.*, 1994). Increased grazing has had a detrimental effect upon the population of certain trees (e.g. *Fagus*) (Bradshaw *et al.*, 1994), as well as affecting the availability of lichens, upon which many of these animals graze on during winter months. The decline in lichens affects invertebrates by removing an important ground insulating layer, as well as affecting some of their food sources.

It is, in the author's view, important to start examining the data represented by these fossils more objectively and investigating their distribution and biology more carefully, starting with investigations of old British collections. It is also necessary to examine similar fossil faunas from across Europe. The insect evidence from Piilonsuo bog, southern Finland, indicates no contemporary non-Finnish components and there are none of the "southern elements" recovered from Thorne and Hatfield Moors. There is thus no evidence in Finland of a warmer fauna between 2900-1700 cal BC, although this does not necessarily negate any possible climate change in Britain. However, a series of comparative sites across Europe might provide some context to British studies.

The disjunct modern distribution of some of the extirpated species indicates that their survival may be largely a matter of chance, surviving in woodland sites with a *continuity* of suitable habitats. With a history of woodland clearance lasting several thousand years, it is not surprising that numbers of specialised insects have become extinct. Although climate change may be partly responsible for the decline and extinction of saproxylics, it remains only one factor, amongst a range of others, which has determined the modern distribution of many of these species. The suggestion that these insects provide insights into climate change or shifts in climatic regimes has yet to be conclusively proved.

CONCLUSIONS

Insects from peatlands have been the subject of various studies documenting their richness and diversity (e.g. Skidmore *et al.*, 1985; Heaver and Eversham, 1991). Most investigations have a relatively short period of study, so at best provide a snapshot picture of communities living in these types of environment. Peatlands, like many other ecosystems, are characterised by shifting vegetational communities and large expansions of their aerial coverage can occur over several thousand years. During such periods many changes occur, including those associated with chemical characteristics of water and peat, and those involving the composition of the flora and insect fauna. Palaeoecological studies offer the opportunity to study these communities on a long-term basis, over the evolution of the peatland.

The study of the fossil insects from the raised mires of Thorne and Hatfield Moors, together with other palaeoecological evidence has enabled the genesis and development of these mires to be reconstructed in some detail. The insects show how shifting vegetational communities have expanded and contracted across the mire with consequent effects upon the insect fauna. The studies also illustrate the incredible faunal richness of these areas and indicates the inadequacy of using plant species as sole indicators of an ecosystem's development and well-being. They are important for assessing and monitoring the overall health of biodiversity and the state of the total environment (Kim, 1993). For instance, whilst *Calluna* heath may be, botanically, viewed as rather featureless, its insect fauna may be diverse and contain numerous species not only associated with *Calluna*, but a suite of many others, including those which prefer warm, sandy places.

The fossil insect work highlights the valuable palaeoecological record of the peat deposits on Hatfield Moors, which have for so long been ignored in favour of its neighbour, Thorne Moors. This historical focus on Thorne Moors has detrimentally damaged the case for the conservation of Hatfield Moors because it was felt it was not necessary to conserve both sites in view of their proximity. However, the palaeoenvironmental record from both sites show marked and significant differences. The mires developed from very different starting points, in different ways and at different rates. This led to the individual characters which are still evident today. These individual characters are highlighted by the results from the correspondence analysis and well-illustrated by the composition of the fossil faunas themselves. Several researchers have suggested that Hatfield Moors today has many affinities to the heathlands of the East Anglian Breckland, most notably by Peter Skidmore (*in press*), in his recent evaluation of the current entomological interest of the Moors. The fossil insect work illustrates that this component has been present since the inception of peats on Hatfield and suggests that the influence of the underlying sand dunes appear to have had a significant impact upon the mire and the development of its associated invertebrate community. Such data also provides valuable data in terms of the sites' long-term management and wetland restoration and highlights the potential of regenerating wet heath in those areas which have been cut-over for peat and gravel extraction.

The palaeoentomological record from the Humberhead Levels emphasises the loss of many elements of the British Coleopterous fauna, both at a regional and national level. This information provides important baseline biodiversity data, rates of extinction, and the nature and scale of human impact on Britain's fauna and flora. Relatively few sites, particularly from natural deposits, have been examined for their entomofauna, but it is quite clear that more research would highlight further losses and extinctions. Whereas it was once assumed that these non-British species were rarities, the fossil work suggests that we are identifying just a fraction of the former range of British invertebrate species. It is therefore important that more natural deposits are examined, to enable a more complete picture of the past biogeography of species to be reconstructed. Analysis of fossil insect material from mainland Europe should be seen as a priority to place the British results within a European context. Very little research has been carried out on European Holocene fossil insect faunas outside Britain, with a few notable exceptions (e.g. Koponen and Nuorteva, 1973; Ponel *et al.*, 1992; Lemdahl, 1997). There are many mires and floodplain deposits which offer potential for this type of approach; such research should be seen as a priority given the constant loss of Holocene peat deposits through desiccation, erosion and peat extraction.

The fossil record from the Humberhead Levels has much relevance for current and future conservation, both in terms of providing details about the invertebrates themselves, as well as the nature of the environments within which they lived. The research has highlighted the nature and diversity of Holocene *Urwald* and illustrates the important habitat provided by abundant dead wood within these systems. The biology of many of these species suggests that they benefit from small-scale disturbances, such as death of trees, small forest fires, as well as larger-scale disturbance such as large forest fires and uprooting of areas of trees during storms. In addition, stand heterogeneity provide buffers against environmental fluctuations (Niemela *et al.*, 1996). Disturbance is a key element within many of these forests, a factor worth considering when "disturbance" registered within palaeoecological records is invariably regarded as anthropogenic in origin (*cf.* Tipping, 1994). However, the fossil record of many of the extirpated Coleoptera indicates that anthropogenic "disturbance" happened all too frequently. The contraction in range or indeed extinction of many faunal elements associated with native *Pinus* woodlands is well illustrated by this research. The importance of fire as a natural agent within the landscape, both within coniferous woodland systems, as well as in *Pinus*-mires and mires and heaths is highlighted. Many species associated with these habitats appear to have a preference for fire-damaged woodland and seem to have suffered a contraction in range, suggesting the former importance of this ecosystem.

There is an urgent need to understand more fully the fossil distribution and biology of these species in order to refine management strategies to conserve these species for the future. Kim (1993) highlights the importance of insects and points out that when a species disappears, other species interacting with it may also become endangered or also disappear. If disruption is severe enough, the whole ecosystem may collapse. The conservation of insects is therefore central to the conservation of any ecosystem.

Further research

The fossils recovered probably represent a fraction of the former biodiversity of the peatlands and floodplains of the Humberhead Levels. In addition, Coleoptera represent just one part of the invertebrate interest of these areas. The fossil record indicates that many other groups are represented and warrant further research. Peter Skidmore's (1995) doctoral work on Diptera has highlighted the potential of this group of insects from fossil deposits and dipterous remains were plentiful in deposits. The continual recovery of new dipterous species on the Moors (e.g. Skidmore, 1992) suggests that the study of such groups offer much potential. Formicidae (ants) are another group which were plentiful and which have received minimal attention in palaeoentomological work. A small study on the ants from Thorne Moors was carried out by an undergraduate student from Leeds University and is discussed by Collingwood and Hughes (1997, 101). A range of species which today occur in southern Britain were recovered, together with an unidentified head capsule closely resembling *Leptothorax corticalis* Mayr. This ant species today lives in central Europe and is found locally on *Quercus* trees and has a relic population in Central Sweden, but is not known to occur in the British Isles.

There are a suite of other possible palaeoenvironmental techniques which have not been yet been applied to deposits in the Humberhead Levels. For example, there is the potential to examine pollution histories in the area and study what effects this may have upon the mire and surrounding areas' vegetation. This type of information is particularly relevant to the management and conservation of these sites. The Humberhead Levels are located in an area with high acid rain deposition (Metcalfe & Whyatt, 1995); the record of pollution levels preserved within the peat deposits could facilitate the management of such sites and identify any potential effects this would have upon any regeneration work.

Other groups of plants and animals have had little attention. For example, the study of testate amoebae (Protozoa: Rhizopoda) may provide actual estimates of water table levels, and more precise predictions of mire hydrological changes in response to future climatic changes (Warner & Charman, 1994; Buttler *et al.*, 1996). This has some very obvious applications within modern hydrological studies of mires, as well as the modern ecology and conservation of these sites.

A relatively recent development has been the use of tephrachronology to detect chronostratigraphic markers within peat deposits (see Blackford, 1996; Dugmore *et al.*, 1996). This technique not only allows securely dated deposits and features to be cross-correlated across individual sites, but it also enables palaeoecological deposits to be linked across an extensive area of the British Isles, facilitating geographically widespread palaeoecological investigations within a secure time frame. The recent discovery of such deposits in northern England (Pilcher and Hall, 1996; Wells *et al.*, 1997) suggests the presence of such tephra layers at Thorne and Hatfield Moors is very likely and suggests areas for exciting new research developments.

Off the mires, research should study the peats beneath the alluvium as a matter of priority. Examination of these deposits may highlight the palaeoecological record of the last 2000 years, which has remained, so far, elusive. New threats to remove peats in these areas mean that palaeoecological and archaeological investigations of these deposits has gained a new urgency.

The floodplain deposits studied have offered the potential of studying landscape change over long periods of time and highlight the urgent need to examine further sequences before desiccation from drainage and agricultural reclamation makes such deposits worthless. Floodplains elsewhere in the British Isles have received scant attention from a palaeoentomological perspective and would undoubtedly benefit from research.

The research has also highlighted the potential of applying new methodological and statistical techniques to palaeoentomological assemblages. There is a wealth of data currently available, which requires some level of re-analysis and synthesis. There has been little effort to collate data and re-evaluate results using different approaches, in an attempt to establish base-line levels of information. In many cases, researchers work in isolation and there is little consideration of any "Big" themes within Holocene palaeoentomology or any agreement of priority future research agendas. This is probably partly due to the very small research community associated with this discipline, but would appear to be an area which requires some attention.

The importance of palaeoecology for nature conservation and regeneration

Whilst the importance and need to conserve the palaeoecological record preserved within mires and floodplain deposits has been recognised by many palaeoecologists (Godwin, 1981; Buckland and Dinnin, 1992; Charman, 1997; Wells *et al.*, 1997; Dinnin and Whitehouse, 1997, Dinnin *et al.*, 1998; Whitehouse *et al.*, 1998), and increasingly by enlightened ecologists and conservationists, the importance of this archive is still not recognised widely enough by some ecologists and conservationists. Proposals for bog regeneration and conservation often taken little heed of the information palaeoecology can offer to nature conservation, nor the scientific value of these deposits (Dinnin and Whitehouse, 1997). The peat record is the *only* source of information recording the processes which have lead to the development of bogs. Peat bogs are the only terrestrial ecosystems which lay down a continuous three-dimensional record of their autochthonous history, as well as that of surrounding animal and plant communities (the allochthonous record). The peat archive thus provides information crucial to the present regeneration activities, as well as future biological conservation planning and management of these and other wetlands, yet proposals for bog regeneration and conservation have often taken little heed of the information contained within the sediments or have provided mechanisms for its survival.

For instance, there is a general lack of scientific information about how peatlands work at the ecosystem level, as opposed to the habitat/species level. Palaeoecology provides such an overview. Research is still in the early stages to examine the processes which have lead to the development and maintenance of raised mires, but recent research has lead to fundamental re-evaluations of traditional models (e.g. Glaser *et al.*, 1997; Korhola, 1995).

On Thorne and Hatfield Moors, the ultimate aim on the areas of peat cutting is to return the sites to their former condition in as many aspects as possible (*cf.* Wheeler and Shaw, 1995). However, the regeneration of cut-over raised mires is still at a pioneering stage (Joosten, 1995); many of the expectations of full mire restoration are based upon the short-term analysis of modern bogs, where peat has begun regenerating over disturbed surfaces. As yet, no evidence is available of successful regeneration in largely cut-over bogs (Joosten, 1995), such as those at Thorne and Hatfield Moors. This seems to be most successful above "white peat" (Joosten, 1995) and there are clear advantages to peat regeneration by attempting such work on as deep peat deposits as possible (Joosten, 1997). Yet government conservation advisers currently advocate the cutting of peat to obtain a *tabula rasa* to create a "restored wetland landscape" (DETR, *pers. comm.*, 1997)

The palaeoenvironmental record thus provides the only opportunity to examine natural processes on a time-scale longer than is possible in real time studies. Based upon spontaneous regeneration of bog forming vegetation, it has been argued that successful colonisation takes around 70 years (Wheeler & Shaw, 1995), although Joosten (1995) has argued on palaeoecological grounds that this may extend to centuries, or it may **never** happen at all. Thus, reference to the past environmental history of a bog can provide an indication of what to expect in terms of the time-scale of change, and the variations of vegetation that have occurred, particularly in the early phases of mire growth (Buckland, 1993). It also enables an assessment of long-term impacts of past human activities on the bogs (e.g. renewal of peat accumulation in abandoned peat workings, Smart *et al.*, 1986). The palaeoecological record suggests that creation of a mire is a process which is the sum of a vast number of biotic and abiotic factors, both external and internal (*cf.* Korhola, 1995). Different types of mire formation may operate in one and the same bog, complicating the evaluation of past initiation dynamics (Korhola, 1995). More importantly, one of the major advantages of a palaeoecological approach is that the record enables a series of "indicators" (e.g. species or assemblages of species) to be identified which may be used as **measures of success** in the management and regeneration of raised mires (Dinnin and Whitehouse, 1997; Whitehouse *et al.*, 1998)

There are a range of other types of information available within the palaeoecological archive which are of use to nature conservation. Fire may have an important role to play in the development of peatlands (Moore, 1996; section 11.8) and may be an integral part of the mire ecosystem. Whilst not advocating that all peatlands should be set on fire, this research highlights the potential of the use of fire in management of such sites. In addition, different regimes which affect ombrotrophic peatlands can be highlighted. For example, the data imply that such mires may not be naturally treeless during episodes of significant regional or global warming; this has implications for conservation of remaining raised mires in the context of current and projected climate change (Chambers, 1997). *Pinus sylvestris* are commonly burnt or cut down where they invade mires, yet the palaeoecological records highlights that these trees form important communities at certain points in a mire's history. They also provide important refugia for invertebrates associated with these trees. The fossil insect record clearly indicates that such policies or actions should be re-evaluated in the light of the palaeoecological evidence. The historical archive also suggests that grazing was widespread on these sites in the past and there is some palaeoecological evidence to support this idea (Chapter 6). Examination of the archive would elucidate the effects of such practises and indicate whether grazing is of value in promoting and sustaining raised mires (Chambers, 1997).

Despite the great potential afforded by a palaeoecological approach, we are still a long way from integrated management which takes into consideration the importance of the Holocene fossil record (*cf.* Buckland 1993; Buckland & Dinnin 1993; Evesham *et al.*, 1995; Whitehouse *et al.*, 1997). This is amply demonstrated by the limited reference to the value of the palaeoecological record of mire development in a variety of publications concerning the restoration of mires (e.g. Fojt & Meade, 1988) and most notably in the government sponsored *Restoration of Damaged Peatlands* publication, where the section on palaeoecology and archaeology amounts to about a page (Wheeler *et al.*, 1995, 30). Indeed, active cutting of peat is advocated to allow restoration. Such an approach has much to commend it to the mineral extraction industries, yet the palaeoecological record would suggest that whilst poor fen can be rapidly achieved, the initiation and development of true raised mire may take several hundred years, and without much of its former invertebrate species diversity. In contrast with Wheeler and Shaw's (1995) over-optimistic ecological approach, Joosten's (1995) salutary comment from the palaeoecological record is that there is no evidence that bogs as self-regulating systems can be restored after severe anthropogenic damage within the human time frame.

It is vital that a landscape such as the Humberhead Levels is considered as an important historic landscape. Much of which can be seen today is the product of human activities as well as natural environmental change. It is important to view all these as part of the whole landscape and that the palaeoecological, ecological, archaeological, historical and nature conservation aspects of the area are considered *together*, allowing an integrated approach to management. The current division of the responsibility of these aspects between two different organisations (English Nature and English Heritage) is particularly inappropriate in an area like the Humberhead levels, where much of the archaeological and palaeoecological interest cannot be protected under current legislation. The present statutory protection of the archaeological resource is restricted to individual monuments and does nothing to protect such areas. Large areas of the landscape cannot be scheduled since they contain no visible archaeology. The fact that many deposits contain information of archaeological interest cannot, at present, be accommodated within the present legislative framework. Yet one could argue that much of the Humberhead Levels' landscape, as elsewhere in Britain, is actually a cultural artefact.

The Humberhead Levels highlight the very real conflicts which can arise between what may be carried out or proposed in the name of "nature conservation" and the needs of archaeology and palaeoecology (Buckland and Dinnin, 1992; Whitehouse *et al.,* 1998). They also highlight the need for much greater and closer liaison between English Nature and English Heritage. In the meantime, much of the precious archive of the mires of Thorne and Hatfield Moors continue to be allowed to desiccate or placed into grow bags. One is left with the question of "Who, in authority, cares for the Holocene?"; the answer, at the moment, would appear to be "No one".

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